



Carbon dioxide emissions and economic growth

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

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THESSALONIKI – GREECE



INTERNATIONAL
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Abstract

This dissertation was written as a part of the MSc in Energy Systems at the International Hellenic University. The issue of environmental degradation is nowadays of paramount significance. Countries worldwide, have to address it, in order to ensure the wellbeing of the population of the planet as a whole and not just in a national level. Economic activities and economic growth are commonly considered to be the driving force of pollution. The relationship though, between economic growth and environmental degradation is a multi-factorial system that can be described by different Pollution-Income relationships (PIR). Exemplarily, the Environmental Kuznets Curve (EKC), the most extensive PIR, is discussed, suggesting that the environmental damage increases as the GDP/capita increases up to a point, where the trend is reversed, forming an inverted U-shape curve. By comparing carbon emissions based on both territorial-based production and on final consumption, it is suggested, that emissions are concentrated mainly in few developed countries, where consumption-based emissions are larger than production-based [2]. Furthermore, a geographical analysis takes place. The global CO₂ emissions, the energy mix and the effects of renewables are also discussed. Fossil fuels combustion contributes approximately 90 % of the total global CO₂ emissions [3]. Renewables sources have increased significantly and supply as much as 16.7 % of the global final energy consumption [4]. Further regulations are needed though, to avoid the possible reemerge of pollution levels, according to the N-shaped curve. The energy sector is a key factor towards influencing emission levels [5].

At this point, I would like to sincerely thank my mother Eriffily, my sister Stella for their support as well as Tiffany Merlin Keffala.

Theodoros Kazakopoulos

14.10.2018

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1 Introduction

The issue of environmental degradation has not been taken too seriously in the past. However, it is nowadays one of the greatest challenge countries have to face as the wellbeing of not just local areas or countries is being threatened but of the planet as a whole. From a local point of view, emissions released in the atmosphere and waste water contaminating drinking water can affect the local ecosystem directly. When the balance of an ecosystem is disrupted, the fauna and flora, responsible for providing us clean air and food is subsequently directly affected. This could lead to disastrous effects on all parts of society, including poverty, starvation, unemployment, health and general wellbeing [6]. This is already happening, from emissions deriving from different polluting establishments, like the chemical industry, causing heart diseases and different types of cancers [7]. On the global point of view, emissions, due to their gaseous nature, don't stay at a local level but they can easily migrate to other parts of the planet. As a result of this, emissions from all countries are accumulated in a global scale causing the greenhouse effect, due to mainly high levels of CO_2 , or acid rain, due to SO_2 . The result of the latter is skin irritations and damages on the buildings and the result of the greenhouse effect is the rise of the global temperature. This leads, in turn, to the melt of the arctic ice, causing the rise of the sea level, endangering many coastal cities and countries [8]. The Intergovernmental Panel on Climate Change (IPCC) reported that in a business-as-usual scenario the mean global temperature is expected to increase by at least 4 °C until the end of the 21st century compared to the pre-industrial levels [9]. A risk of an even greater temperature increase is not ruled out [10]. There is a consensus in the literature that this temperature increase should not be more than 2 °C to avoid the risk of irreversible climate change [11]. The issue of climate challenge is not a moral issue but a question of human survival, and the world as we know it.

Economic activities and economic growth are commonly considered to be the driving factor of pollution, following the simplistic approach, that increased production leads to increased pollution. However, the relationship between economic growth and environmental degradation is a multi-factorial system that could behave differently in different times and different places. Some believe that economic growth will inevitably lead to

the destruction of the environment, some believe that economic growth can lead to a cleaner environment after a certain threshold [12]. Economies will continue to develop further and with them production and consumption will grow as well. Therefore, it is important to better understand this relationship in a structured and organized way, in order to be able to forecast the results of our economic activities and better plan our future.

The inverted-U curve, Environmental Kuznets Curve (EKC), (Figure 1) is inspired by the relationship between economic growth and income inequality suggested by Kuznets in 1955 [13]. The EKC was first introduced in the World Development Report in 1992 [14]. Its theoretical background is based on the results of industrialization, namely the shift from agricultural production in rural areas to industrial production in urban areas. With higher degree of industrialization pollution increases, due to industrial production intensification. With higher income levels, more technological achievements aiming to reduction of emissions can be achieved. This is called the technological effect and describes the result of technological achievements towards a more effective production [15, 16]. At the same time service-centralized production is favored, slowing down the increase of pollution and eventually leading to its reduction. This is called the composition effect, and describes the shift of an industry-focused economy towards a service-focused economy [17, 18]. Furthermore, the demand of the consumers for a cleaner environment favors a higher political interest towards environmentally friendly investments [12]. Different types of regulations, including emission charges or standards and property rights, could be applied in either national or international level to limit pollution [19]. The climate accord in Paris, the COP21, was an important effort that took place, in order to monitor and set commitments for global warming mitigation. Two years later, the COP23 in Bonn took place and “sought to maintain the global momentum to decouple output from greenhouse gas emissions” [20]. However, whether or not decoupling occurs and at which extent is a matter for debate. When emission levels drop, climate sceptics support that global warming concerns are exaggerated. When emission levels rise environmental groups point out that not enough measures and regulations are in place to avoid environmental destruction. Exemplarily, when Germany’s emissions rose in 2016, many were suggesting that the country will not meet its 2020 climate targets [21].

The EKC-pattern is one of the first pollution-income-relationships and is widely used [22]. Nonetheless, it has received a lot of critique over the years, concerning the implicit assumption of the EKC-speculation about the normal distribution of income [23] or the causality between income and pollution [24]. Further criticism considers the utilization of only panel-data and not time-series data [25] as well as the analysis of only the production and not the consumption evolution [26]. An extension of the EKC-pattern is the N-shaped relationship, that could better describe the long-term correlation between economic growth and environmental degradation than the former. The N-shaped curve implies a behavior that amplifies the income-environmental pollution relationship in the long term [27, 28]. Extending the EKC-pattern, namely the inverted-U shape, the N-shaped curve suggests that a second turning point would appear, where pollution would start rising again as economies grow bigger. The stage after the second turning point is characterized by high income levels with low economic growth rates, where the technological improvements and/or regulations are apparently inefficient and/or insufficient [29].

The Brundtland curve hypothesis (Figure 6) is another suggested curve modeling the impact of the economic growth on the environment. This hypothesis was published in 1987 in a World Commission on Environment and Development (WCED) report and illustrates an inverted EKC, namely a U-shaped relationship of GDP/capita and pollution [30]. In this hypothesis, it is described, that economies driven by increased production will inevitably destroy the environment. Similarly, the environmental Daly curve also predicts the inevitable environmental destruction. It is described by an exponential increase of the environmental damage with increase of GDP/capita (Figure 7). Natural resources could be either non-renewable or renewable. The first will inevitably be depleted in the future. With always growing economies at some point the consumption rate of a renewable resource will be higher than the rate of its renewal, resulting to its depletion. Therefore, an alternative should be proposed, namely a steady-state type of economy that will not consume all natural resources and therefore will lead to a sustainable development[31].

There is not one pollution-income relationship that fits perfectly to the data of all countries. The geopolitical factor is also affecting them and therefore a geographical analysis is also necessary to better understand and evaluate the aforementioned relationship in each country. Numerous studies based on empirical data for different countries world-

wide are examined. In some cases, the EKC-pattern is verified, whereas in other cases the pollution levels keep increasing monotonically as economies grow bigger[32-34].

Focusing on global pollutants, like CO₂ emissions, and not just on local pollutants, it is important to take into consideration how they are measured. Many countries, like Germany, import pollution-intensive goods from countries like China. This results to a decrease of emissions based on production in Germany and their subsequent increase in China. This shift of pollution-intensive production to other countries causes no difference in global emissions. The Kyoto protocol, rests on emissions commitments in national borders and therefore, the correlation between national activities and global emissions has been weakened due to national and global production networks. Therefore, many studies work with data that reflect cross border production correlations, studying the relationships between GDP/capita and CO₂ emissions/capita from fossil fuel combustion based on production and consumption. By associating production-based emissions in one country and consumption-based emissions in another, an entire carbon chain could be defined[35].

Next, the different sources of CO₂ emissions and the energy mix should be discussed. Fossil fuels and cement clinker production processes, the largest source of non-combustion-related CO₂ emissions) contribute to CO₂ levels. Incorporation of the nuclear energy in the energy mix, is an effective way to reduce CO₂ emissions, with the USA, France and Japan leading the way. After the Fukushima accident though, Japan and other countries, like Germany, changed significantly their energy mix, by increasing the share of coal and/or renewable energy sources. Total renewable sources have increased significantly as well and supply as much as 16.7 % of the global final energy consumption[4]. Solar energy showed also a significant increase by 75 % globally in 2011. Hydropower however, exhibited the smallest increase. The energy sector is a key factor towards influencing emission levels [5]. New policies and regulations, aiming to increase the share of nuclear and renewable energy sources affected the trends in CO₂ emissions globally. Renewables as well as biofuels played an important role in decreasing emissions, although their share is still very small, they are increasing with accelerating speed. Utilization of renewable energy sources combined with energy savings and optimizations would lead to a further decrease of CO₂ emissions[36]. The technical obsolescence should be taken into consideration, since it can diminish the long-term positive effect of the innovation achievements[37].

In this study the different Pollution-Income Relationships (PIR) are discussed extensively. The different patterns, as well as the different effects influencing them. Additionally, production-based and consumption-based emissions are differentiated and discussed to better understand the local activity and the global emissions. Next, a geographical analysis takes place for the regions of Europe, Asia, Middle East, the Americas and Africa. The energy mix and CO₂ emissions in a global level are also discussed. The contribution of all the major-polluting countries is discussed as well as the trend by introducing renewable energy sources in the energy mix.

2 Pollution-Income Relationships (PIR)

Economic activities and economic growth are commonly considered to be the driving force of pollution, following the simplistic approach, that increased production leads to increased pollution. However, the relationship between economic growth and environmental degradation is a multi-factorial system that could behave differently in different times and different places. Some believe that economic growth will inevitably lead to the destruction of the environment, some believe that economic growth can lead to a cleaner environment after a certain threshold [12]. Economies will continue to develop further and with them production and consumption will grow as well. Therefore, it is important to better understand this relationship in a structured and organized way, in order to be able to forecast the results of our economic activities and better plan our future.

In this sense, a lot of studies have been performed trying to define the way economic growth and pollution are related. Different patterns have been identified, trying to explain this relationship with sometimes diverging results. Usually, the dependent variable on the vertical axis is a generalized indicator of environmental damage or pollution, like emissions air quality indicators (CO_2 - one of the main greenhouse gases, SO_2 or NO_x), water quality indicators (concentration of heavy metals, pathogens) or other environmental indicators like deforestation or access to drinking water. The independent variable on the horizontal axis describes the economic growth per capita, calculated by dividing the GDP by the population of the economy. The two variables on the axis can be used directly as x and y or they can be transformed into logarithms using $\ln(x)$ and $\ln(y)$. This way zero or negative indicators are avoided [38]. Nonetheless, the researchers always choose the model and the functional form that fits the data the best and gives more insights on understanding and explaining the findings [39].

The generalized formula of these patterns is a third-degree polynomial function (Eq. 1).

$$y_{it} = a_i + b_1x_{it} + b_2x_{it}^2 + b_3x_{it}^3 + b_4z_{it} + e_{it} \quad \text{Eq. 1}$$

where x : GDP/capita, y : environmental damage, $i=1, \dots, n$ countries, $t=1, \dots, T$ years, a_i : a constant term or country-specific intercept, b_i : estimated coefficients of the k explanatory variables, z : a control variable that might influence y , and e : the error term. The coefficients' values could be negative, positive or equal to zero. Different combinations are identified and described in Table 1.

Table 1: Different cases of correlation between GDP/capita and environmental damage over different values of the b_i coefficients.

	Values of coefficient (b_i)	Correlations between x (GDP/capita) and y (environmental damage)
1	$b_1=b_2=b_3$	No correlation
2	$b_1>0$ and $b_2=b_3=0$	Linear correlation – monotonically increasing
3	$b_1<0$ and $b_2=b_3=0$	Linear correlation – monotonically decreasing
4	$b_1>0$, $b_2<0$ and $b_3=0$	Inverted U-shaped curve (EKC)
5	$b_1<0$, $b_2>0$ and $b_3=0$	U-shaped curve (Brundtland Curve)
6	$b_1>0$, $b_2<0$ and $b_3>0$	N-shaped curve
7	$b_1<0$, $b_2>0$ and $b_3<0$	Inverted N-shaped curve

2.1 The Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve (EKC)(Figure 1) is inspired by the relationship between economic growth and income inequality, suggested by Kuznets in 1955 [13]. The EKC was first introduced in the World Development Report in 1992 [14]. It was used to correlate the atmospheric concentrations of sulfur dioxide (SO_2) and the per capita Gross Domestic Product (GDP) in 47 cities distributed over 31 countries [14]. The GDP and sulfur dioxide concentration are positively correlated up to a point, where the trend is reversed, forming an inverted U-shape curve. The EKC is nowadays applied to general environmental pollution worldwide and not only to sulfur dioxide concentrations and urban areas. The main philosophical background of the EKC is reflected in Beckerman's view about the influence of economic growth on environmental degradation: there is "clear evidence that, although economic growth usually leads to environmental deterioration in the early stages of the process, in the end, the best and probably the only-way to attain a decent environment is the most countries to become rich" [40].

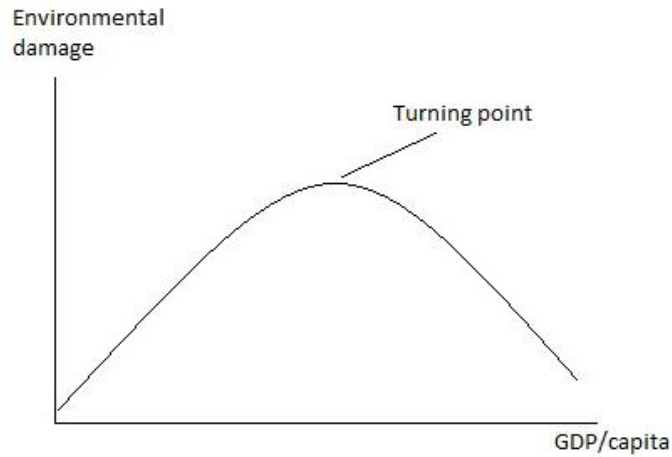


Figure 1: The Environmental Kuznets Curve (EKC) [1]

The theoretical background of the EKC is based on the results of industrialization, namely the shift from agricultural production in rural areas to industrial production in urban areas. With higher degree of industrialization pollution increases, due to industrial production intensification. With higher income levels, more technological achievements aiming to reduction of emissions can be achieved. At the same time service-centralized production is favored, slowing down the increase of pollution and eventually leading to its reduction. In addition to this, the consumers' demand for a cleaner environment leads to a higher political interest to favor environmentally friendly investments [12].

The EKC-curve is a specific form of PIR. The turning point is calculated (Eq. 2).

$$x^* = -\frac{b_1}{2b_2} \quad \text{Eq. 2}$$

There are multiple effects that influence at the same time this relationship. In order to better understand the evolution of the EKC, the different phenomena influencing it, are presented in Figure 2 and are discussed.

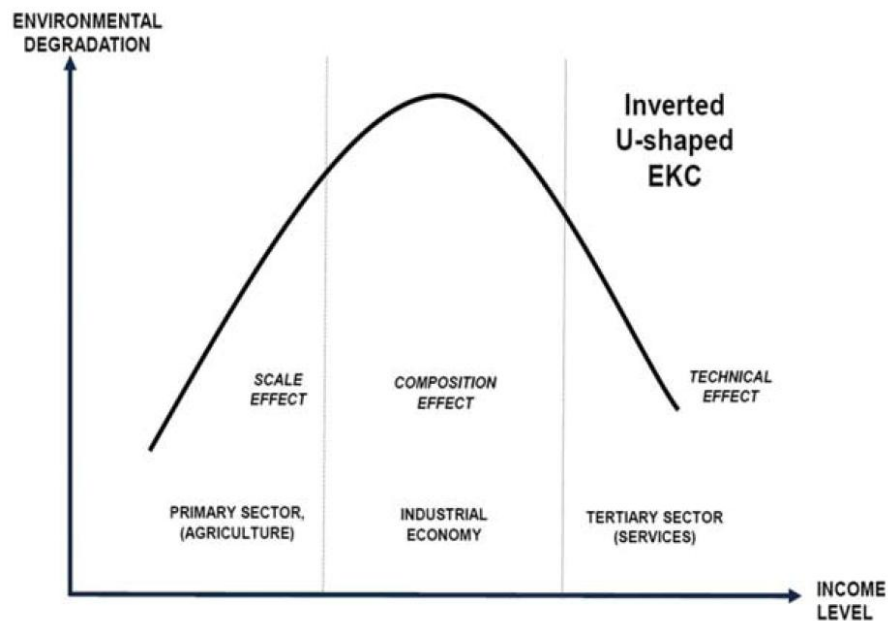


Figure 2: The EKC-curve divided into three parts, according to the dominant effect influencing the trend of the curve.

2.1.1 The scale effect and income inequality

The environmental damage increases initially as the GDP/capita grows – this phenomenon is called the scale effect. As economies grow, the production output is increased, which requires increased input, namely more natural resources. The sum effect of higher consumption of natural resources and the higher output, leads to increase of pollution levels [41]. Furthermore, income inequality is identified as another crucial factor. With increasing economic growth, the income inequality is expected to increase [28]. Higher levels of income inequality in turn, leads to higher levels of environmental damage, since those who suffer from pollution will not be able, in terms of economic power, to impose environmental regulations on those who benefit from pollution [42].

Different mechanisms have been identified, that counteract the scale effect and income inequality, namely the steady increase of pollution by increasing economic growth. The following effects occur simultaneously, and the net result is that the increase of environmental damage slows down as the GDP/capita increases and eventually will start disappearing.

2.1.2 The technique effect (technological progress)

The technological effect describes the result of technological achievements towards a more effective production. According to basic economic theory, the industry is always

trying to sell its products and services at lower prices and maximize profits. To achieve this, the production costs must be decreased. This serves as the driving force to invest into research of new technologies or optimizing the existing ones, aiming to the decrease of production costs. More effective production necessitates less input and therefore leads to less pollution [15, 16]. In this sense the environmental profit could be considered as a side effect next to the economical profit, that could be still utilized.

Moreover, technological progress towards reduction of energy intensity should also be discussed. It surfaced as a crucial factor after the oil crises in the 1970s and promoted awareness about energy conservation. The oil-dependent economies were forced to invest on new technologies towards energy intensity reduction [43, 44]. Overall, energy intensity has shrunk over time but this is due to the increased utilization of higher quality fuels and not fossil fuels [38].

2.1.3 The composition effect

The composition effect describes the shift of an industry-focused economy towards service-focused economy. With economic growth, industry and governments increase their need of varied services that are vital in the modern society, like practices of the law, engineers and doctors. Moreover, with economic growth the population increases the consumption of household related services. There are cases, that increase the GDP/capita without increasing pollution. In other words, economic growth does not necessarily lead to pollution increase if the composition of output is changed (relative change in the composition of products and services produced) [17, 18].

2.1.4 The international trade effect and the displacement hypothesis

The technological and composition effect are more profound in richer and more developed countries rather than in developing countries. According to basic trade theory, it is suggested that countries specialize in products can produce relatively efficiently. Therefore, developed countries pollute less, due to their high-technology industry as opposed to the low-technology industry in the developing countries. As a result of the international trade, the global production is divided into “dirty” and “clean” or “green” production [45]. This phenomenon leads only to local changes in pollution levels, but the global levels remain the same. This is described by the displacement hypothesis. Production cost and regulations are different in this “pollution havens” and therefore they can further intensify the displacement hypothesis [12].

2.1.5 The demand for a cleaner environment

With economic growth, income increases together with the willingness from the customer's side to pay more – Willingness To Pay (WTP) – for a cleaner environment. This is expressed by purchasing environmentally friendly products that usually cost more. Environmentally conscious consumers choose to donate to organizations or vote for political parties that help promote environmental benefits. The willingness to pay for a clean environment increases relatively more than the increase in income and therefore pollution decreases[46]. In order to quantify the consumers preferences with respect to shift of environmental quality over income changes, Eq. 3 was introduced[47].

$$\eta = \frac{(\Delta E)\%}{(\Delta Y)\%} = \frac{\partial E}{\partial Y} \frac{Y}{E} \quad \text{Eq. 3}$$

where η : the demand of environmental quality, E: the quantity of environmental good demanded and Y: the income. The following cases are identified:

Table 2: Classification of E based on different values of η .

	Values of $ \eta $	Values of E
1	>1	E is a luxury good (environmentally friendly)
2	<1	E is a normal good

It is generally accepted, that for the first case, environmentally friendly goods are considered to be luxury goods[12]. Because it is difficult to measure E, the quantity of environmental good demanded, the Willingness To Pay (WTP) is alternatively defined. It measures the change of willingness to pay for an environmentally friendly, more expensive, product in response to the income change. It is shown that the income elasticity of WTP is less than unit, while the income elasticity of demand on environmental quality is marginally over unit [47]. In order to prevent environmental damage, the consumers need to exercise sufficient environmental efforts as their income increases, because even the most innovative technologies will not be sufficient to prevent environmental destruction. Moreover, the shift in consumers' preferences is affected by multiple variables, like spatial and time conditions, and therefore is difficult to be predicted[48]. For example, soil pollution of a distant not populated area would not be a concern of the inhabitants of a clean city or if the cost of pollution can be transferred to a remote future

then the consumers are usually not motivated to change their consumption patterns towards more environmentally friendly ones [46].

2.1.6 Strengthened environmental regulations

Different types of regulations, including emission charges or standards and property rights, could be applied in either national or international level to decrease pollution levels [19]. It is suggested that state pollution would not decrease unless environmental regulations are strengthened [49]. In developed countries, where income grows, people tend to demand a cleaner environment. This leads to politicians adopting and voting more environmentally friendly regulations, which in turn lead to decrease of pollution. This is in line with the median voter theorem, introduced by Black in 1948 [50].

Researchers have focused the last years their studies to correlate specifically CO₂ emissions with GDP/capita. Results are mixed but in most cases CO₂ emissions increase monotonically as the economies grow, namely they don't follow the EKC. This could be due to the fact that CO₂ emissions are closely correlated with energy consumption, which is vital for economic growth. Furthermore, the effects of CO₂ emissions cannot be localized due to their gaseous nature [24, 32].

2.2 Criticism of the Environmental Kuznets Curve (EKC)

The EKC-pattern is one of the first pollution-income-relationships and is widely used[22]. Nonetheless, it has received a lot of critique over the years, concerning the implicit assumption of the EKC-speculation about the normal distribution of income [23] or the causality between income and pollution [24]. Additional criticism considers the utilization of only panel-data and not time-series data [25] as well as the analysis of only the production and not the consumption evolution [26]. In this section, this discussion is reviewed and presented in a structured way.

2.2.1 Income distribution

Multiple studies utilize the EKC with the economic growth as the independent variable. The latter is calculated by dividing the GDP with the population of the economy (GDP/capita). That way the average income of different countries is calculated and combined into a common EKC-pattern and ultimately the average income level that corresponds to the turning point is calculated [12, 18, 39]. In this methodology, there is an

inherent problematic, namely the pre-assumption that the world income is normally distributed. There are numerous studies showing that this is not true. They suggest that there are much more people below world mean income than above it [23, 38, 51]. According to EKC, there is a turning point at a certain level income above which environmental damage starts to decline. This level of income is not achievable, since the majority of the people's salaries are below the mean income. Therefore, the estimation of the turning point is of little consequence [52]. Measuring world income distribution (or income inequality) is a difficult task and different methodologies are applied that could lead to different results, in regards to income inequality worsens or betters over time [53]. All agree though that income is not normally distributed [52].

In another study, the average GDP/capita in constant 2005 US\$ was utilized to calculate the world income distribution among 195 countries. Furthermore, the average GDP/capita, PPP in constant 2005 international \$ was utilized to calculate the world income distribution of 182 countries. Purchasing Power Parity adjusted incomes (PPP), compares the currencies of different countries through a "basket of goods". The different currencies are in equilibrium when a basket of goods, taken into consideration the exchange rate, is priced the same in each country. The main limitation of the PPP approach is that people in different countries consume typically different baskets of goods and therefore the differences in the quality of goods are difficult to be depicted. Additionally, different consumption patterns contribute into environmental damage to a different degree and therefore the latter is not comparable. The results of this study are presented in Figure 3. They show that the world income does not follow a normal distribution in both calculations. Almost 83% of the world population lies below the global average of countries average GDP per capita in 2005, reaching the value of 11907 in constant 2005 US\$ and the value of 11971 in constant 2005 international \$[52]. Instead of using average income as an indicator of economic growth, the median income is suggested instead. This would solve the comparability issues [23].

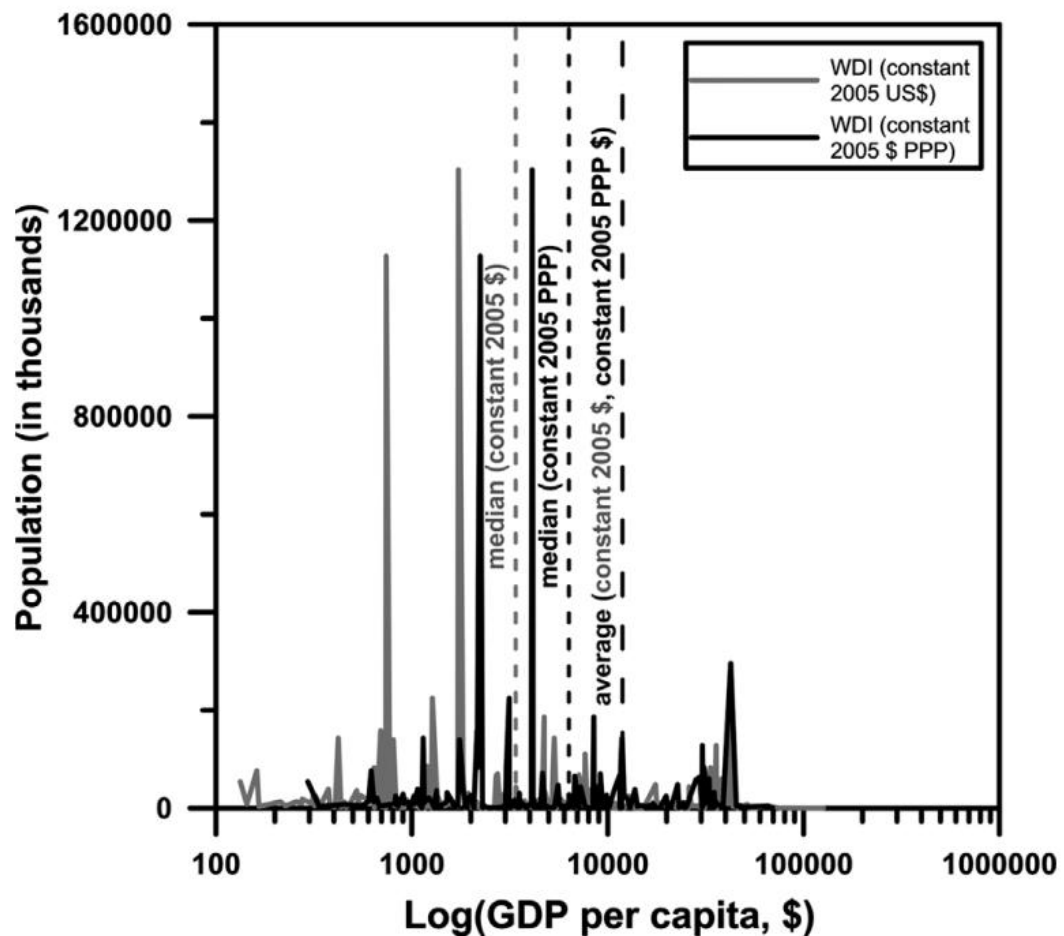


Figure 3: World income distribution in 2005. The GDP per capita are in constant 2005 US\$ and PPP constant 2005 international \$, respectively. The average GDP per capita is depicted with one line since the difference between the averages in both calculations is small [52].

2.2.2 Growth of developing countries compared to developed countries

In the EKC the developing countries lie on the upward section with environmental footprint whereas the developed countries lie on the downward section. Whether or not the developing countries will follow the growth pattern of the developed ones is the matter of criticism. One study suggests that the EKC-pattern is valid only for the developed countries before the oil crises in the 1970s. The great majority of the countries becomes less energy-efficient and are facing difficulties to grow, due to their history of being exploited by colonialists and their lack of geopolitical power. Therefore, the historic growth patterns of the developed countries cannot be necessarily followed by the developing ones in Africa[54]. Moreover, the developed OECD countries can better adopt to world crises, like the oil crises, compared to the developing ones, since the former possess more advanced technologies and more favorable financing [55].

Additionally, the pollution haven hypothesis should be considered. In this, the countries that grow significantly, pollute significantly as well. At some point they will probably attempt to decrease their pollution by importing more goods from countries, where environmental regulations are less strict. Over time more countries will grow and shift their pollution-intensive industries into developing ones. At some point the developing countries that pollute, won't be able to shift their pollution to other countries and they will have to find another way to reduce it [23, 38]. This could be further intensified, if the demand of pollution-intensive goods from the developed countries remains at high levels [56]. Concluding, the international conditions could drastically change in the future. There is no guarantee that the developing countries will follow the same growth patterns as the developed ones. This is a speculation, with arguments pointing to both directions.

2.2.3 Consumption pattern

The scale, technique and composition effect explain the EKC-pattern to a certain extent but not fully, due to the fact that they do not consider the consumption side [26, 57]. The demand defines the extent of production. In case that imports satisfy the domestic consumption, then this effect should not be considered in an EKC-analysis focusing only on the domestic production [26, 56]. Thereafter, changes in the income elasticity of demand for pollution-intensive goods should be taken into account, when applying the EKC-pattern. In case that income elasticity is not decreasing, the demand, in developed countries, is satisfied by the production in developing countries [56]. It should be noted that if the final consumption remains pollution-intensive, then the positive effects of production improvements, like technological progress or structural changes, might not be sufficient and the end result would be further increase of pollution. Developed countries may have reached significant levels of energy efficiency and production optimization in general, but they still consume energy-intensive goods [58].

2.2.4 Pollution of services

It is assumed that poorer economies start with agricultural production, which pollutes relatively little and as they grow bigger they shift gradually to industrial production, causing heavy pollution, and ultimately to the services which pollutes less than industrial production. This is based on the assumption, that services are information-based and less material-based and therefore do not pollute. This is a simplified hypothesis that does not take into consideration the whole life cycle of the service [18]. However, for a

service to be sold, an office in a building with heating is required. Power to run computers and having internet is a prerequisite. Internet is provided by another company, which in turn needs electricity to power their infrastructures. Additionally, the employees need to commute, usually by car or train. One needs to consider the pollution created due to all the aforementioned factors in order to be able to depict the real picture[59, 60]. In Figure 4, the change of GDP composition as value added by the sectors of services, industry and agriculture is presented over time exemplarily for the case of the USA. It is clear that the service sector, including the transportation and commercial sector, is increasingly attributing to the overall CO₂ emissions over the course of time[52].

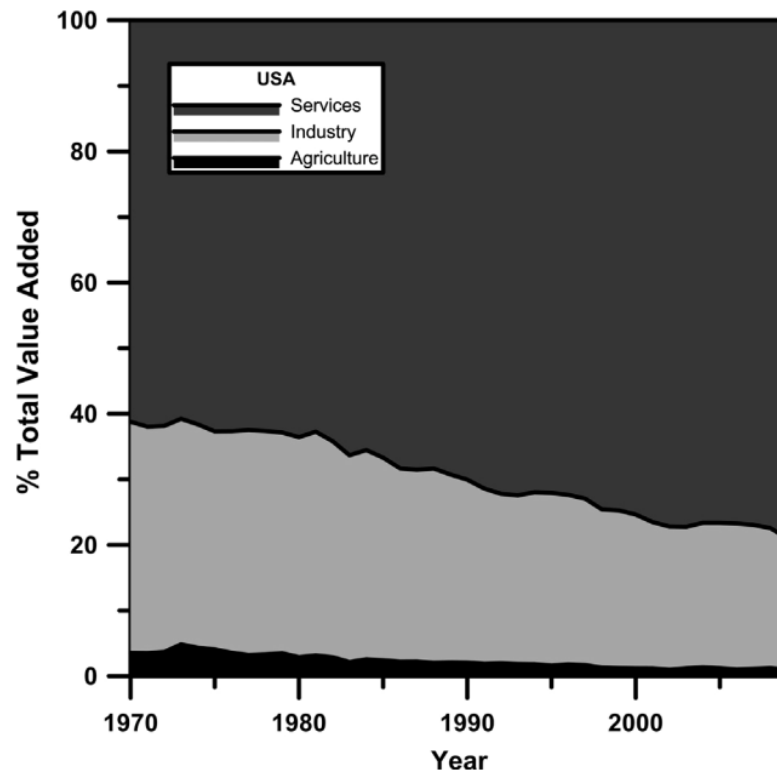


Figure 4: U.S.A.: GDP composition as value added by sectors 1970-2009 (Data source: World Bank data) [52].

Furthermore, the transportation sub-sector is included into the service sector[59, 61]. The transportation sub-sector is responsible for almost 25% of the global energy-related CO₂ emissions [62]. Considering this, the shift to the service sector for countries like the USA has a minor effect to the overall emissions [63].

2.2.5 Local and global pollution

The EKC-pattern seems to be verified with pollutants having low and local short-term abatement cost [24]. Such pollutants, like Sulphur dioxide and particulates, have nega-

tive effects on the quality of life and health and their effects can be perceived rather easily and fast by the communities. Their levels can be decreased at relatively low cost [12, 18, 24, 39]. On the other hand, pollutants with long-term effects, little effect on quality of life and health and a high abatement cost, do not follow the EKC-pattern [12, 24]. This appears to be especially true for greenhouse gases. The majority of the studies suggest a positive relationship between emissions of greenhouse gases and economic growth and not an inverted-U correlation, namely EKC-curve [12, 32, 57]. Concluding, the critical point, when examining the correlation between environmental degradation and economic growth, seems to be the relative spatial effect, the relative health effect and the relative abatement cost effect of a specific pollutant. The weighting of such characteristics could lead to an EKC-pattern for one pollutant in one country but not necessarily for other pollutants within the same country at the same time [24].

2.2.6 Direction of causality

Recently, many studies focus in the direction of causality among the variables reporting various findings, depending on the sample and time that are investigated. With respect to pollution and income, causality runs from emission to income in developed countries in North America and Western Europe. In Central and South Africa as well as in Japan and Oceania it runs from income to emissions. Interestingly, in countries in Asia causality is reported to be bi-directional[64]. With respect to energy consumption and income neutral correlations were reported in UK, Sweden and Germany, while in USA a bi-directional causality. In Canada, Belgium and Switzerland an un-directional causality was found, while in France, Italy and Japan a reverse un-directional causality[52].

2.2.7 Other econometric issues

Many authors criticize empirical EKC-studies on various econometric issues. The data on environmental degradation are usually poor in quality and not comparable [23]. There are different methods to estimate the CO₂ emissions, which leads to different results that deviate from the real values [65]. Additionally, the scarcity of results over a long period of time, restricts to a significant extent the EKC-studies [66]. Therefore, many studies utilize panel data instead of time-series data. Panel data [25]. Panel data assume that data from all countries are homogeneously distributed and is a way to increase the sample data. Finding a turning point of the EKC-curve does not necessarily mean that each country alone will follow the same estimated pattern, since some poor

countries may not provide such evidence yet[66]. Instead EKC-studies with longer time-series data should be utilized in order to be able to apply an EKC-curve for each country individually[66, 67].

Furthermore, the omitted variable bias should be taken into consideration in respect to i) the differences between the parameters of the random-effects and fixed-effects models using a Hausman test, ii) the differences between the estimated coefficients in different sub-samples and iii) the tests for serial correlation[38]. Serial correlation, or autocorrelation, suggests that the error terms are dependent from one another[52]. Additionally, the early EKC-estimations may involve non-stationary variables that must satisfy the cointegration property, in order for regression to be valid [68]. GDP/capita, used as an indicator for economic growth, is a non-stationary variable used in EKC-studies and therefore invalidate the use of standard unit root tests and cointegration techniques in times-series or panel data, leading to questionable results[69, 70].

Another econometric issue is the fact the environmental degradation could hinder economic growth [23, 24]. It is reported, that economic growth in OECD countries lead to high emissions of greenhouse gases, which in turn constraint further economic growth [71].

Moreover, emissions, due to their gaseous nature cannot be considered to remain strictly to one country but it could migrate to neighboring ones. If for example CO₂ from country A migrates to country B then emissions in the former are less and in the latter correspondingly more. This phenomenon is not taken into consideration in many EKC-studies[68]. Therefore, spatial effects of emissions might be an incorrect interpretation of the emission levels in some countries over time.

2.3 The N-shaped relationship

The N-shaped relationship is an extension of the EKC-pattern, which could potentially better analyze the long-term relationship between economic growth and environmental degradation. Schematically, it is presented in Figure 5. The N-shaped curve implies a behavior that amplifies the income-environmental pollution relationship in the long term[27, 28]. Initially, as the economy grows pollution increases also hand in hand. This is explained by the scale effect. When the production output increases, it requires increased input, namely more natural resources. The sum effect of higher consumption of natural resources and the higher output, leads to increase of pollution levels [41]. Once

the economy has grown a turning point would appear due to different reasons, like technological advancements, energy intensification, green and sustainable production processes and the gradual shift to the service sector. These effects would lead in time to a further decrease of pollution. Up to this point this is the standard EKC-pattern. The N-shaped relationship suggests that a second turning point would appear, where pollution would start rising again as economies grow bigger. The stage after the second turning point is characterized by high income levels with low economic growth rates, where the technological improvements and/or regulations are apparently inefficient and/or insufficient [29]. The second upward pollution branch is considered to appear when the margin for successive improvements in the distribution is exhausted, namely when there are diminishing returns in terms of technological change reducing pollution because of “obsolescence” [28]. This phenomenon will be discussed into more details in section 5.3.

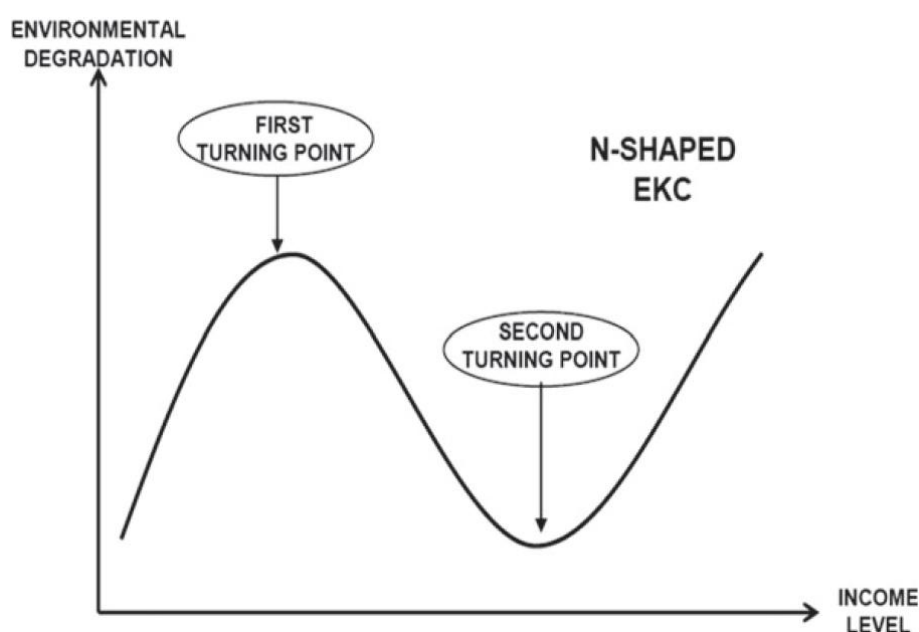


Figure 5: The N-shaped relationship – an extension of the EKC[29].

2.4 The Brundtland curve hypothesis

The Brundtland curve hypothesis (Figure 6) is another curve modeling the impact of the economic growth on the environment. This hypothesis was published in 1987 in a World Commission on Environment and Development (WCED) report and presents an inverted EKC, namely a U-shaped relationship of GDP/capita and pollution[30].

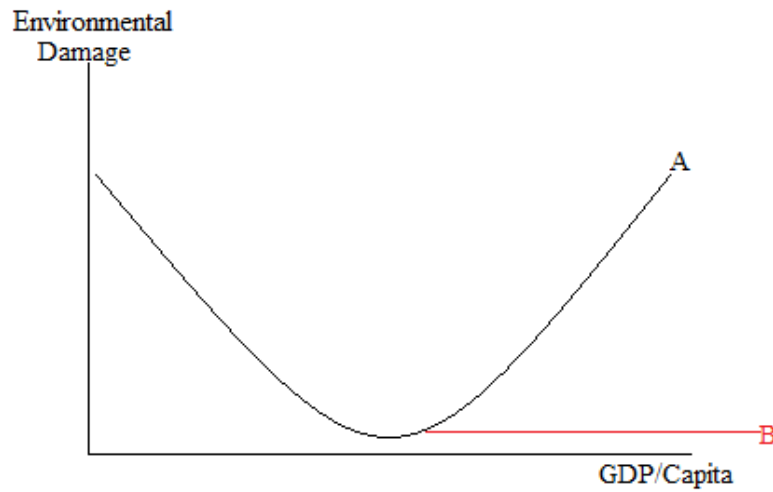


Figure 6: The Brundtland curve[1].

According to this hypothesis, the protection of the environment is not a priority in countries in poverty, due to various socio-economic reasons. The population needs to over-exploit sensitive lands and natural resources in order to survive, leading to high environmental damage [33]. Poverty being the main reason for environmental pollution, with increasing GDP/capita the first decreases to reach a minimum. At this point increased consumption is dominant which leads to increased production and hence pollution starts to increase until it reaches or eventually will become higher than the initial level. The environmental damage resulted by increased production is as harmful as the one resulted by poverty [72]. This is pessimistic path, marked as “A” in Figure 6. The optimistic path marked as “B” is an alternative prediction. This path would be possible only if green technologies were of high priority, so that developed countries invest intensively in innovative, green technologies to counteract the surging pollution levels [73]. The willingness of developed countries to invest into these technologies, that will enable decrease of pollution, is of paramount importance [33, 72].

2.5 The environmental Daly curve hypothesis

In this hypothesis it is described, that economies driven by increased production will inevitably destroy the environment. The environmental Daly curve predicts an exponential increase of the environmental damage with increase of GDP/capita (Figure 7). Natural resources could be either non-renewable or renewable. The first will inevitably be

depleted in the future. With always growing economies at some point the consumption rate of a renewable resource will be higher than the rate of its renewal, resulting to its depletion. Therefore, an alternative should be proposed, namely a steady-state type of economy that will not consume all natural resources [31]. Additionally, it is suggested, that the incentive for green technologies is not sufficient to decrease pollution levels. Even in highly developed countries, where the willingness and technology will be present, the environmental destruction could be irreversible[74].

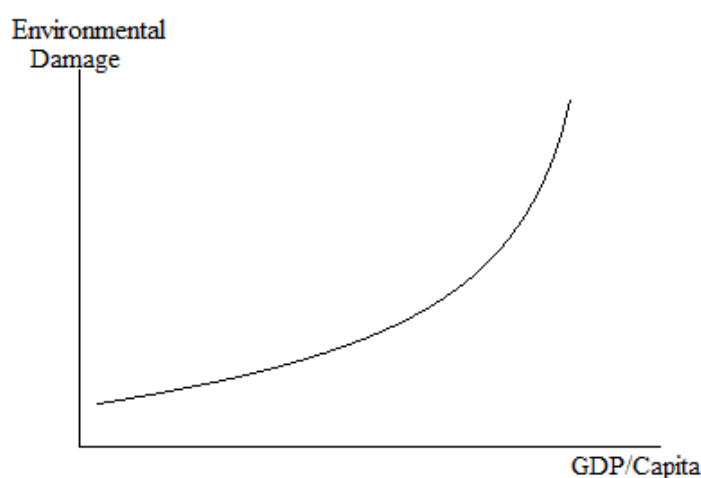


Figure 7: The environmental Daly curve[1].

2.6 The problematic of cross-sectional studies

The different theories mentioned so far are based on cross-sectional studies, that only consider data that differ in space and not in time. Each country's slope, at the time the data were obtained, does not necessarily have to be tangent with the slope of the cross-sectional curve, where the country is placed. This means that the model cannot describe the relationship between economic growth and pollution in each country (Figure 8). In order to overcome this limitation, time-series studies are requested instead of cross-sectional data. The problem though lies in the fact that they require data from a long-period of time. In the case of environmental pollution they are non-existent[12, 75].

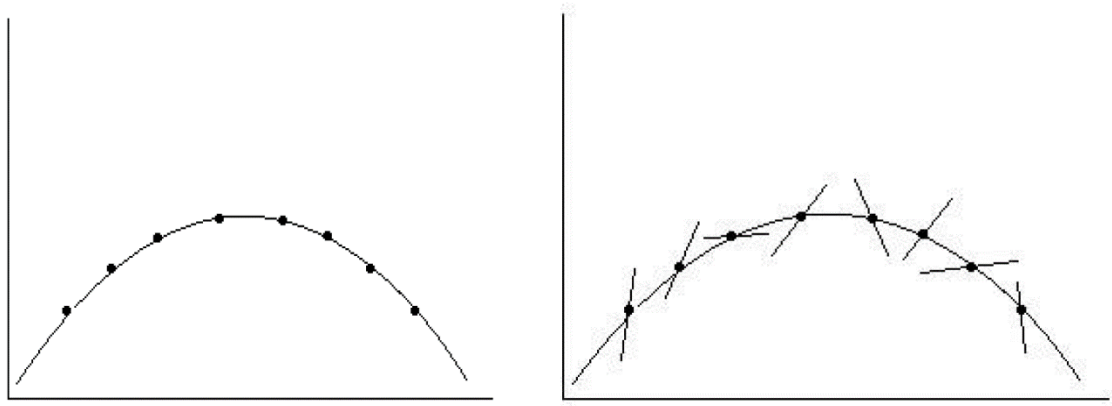


Figure 8: A) The dots represent different countries along a curve based on cross-sectional data and B) The slopes for each country is not tangent to the slope of the cross-sectional curve at that particular point [1].

Furthermore, it should be noted that the countries positioned on the top of the curve are all Latin American. Therefore, the shape of the inverted U curve could be only an artefact, since these countries pollute more having higher GDP/capita due to socially structural reasons [75].

2.7 Concluding remarks and summary

The relationship between economic growth and the environment is a relatively new subject in economics and due to this, there are not many established theories on the area. In this study the most acknowledged theories were discussed and are summarized.

The Environmental Kuznets Curve (EKC) is the most extensive theory and its theoretical background is based on the classical economic topics, like income elasticity, trade and competitive markets. The environmental damage increases as the GDP/capita increases up to a point, where the trend is reversed, forming an inverted U-shape curve. Although the EKC-curve is widely used, it has received a lot of critique over the years, concerning the implicit assumption of the EKC-speculation about the normal distribution of income [23] or the causality between income and pollution [24]. Additional criticism considers the utilization of only panel-data and not time-series data [25] as well as the analysis of only the production and not the consumption evolution [26].

The N-shaped relationship is an extension of the EKC-pattern, which could potentially better analyze the long-term relationship between economic growth and environmental degradation. The N-shaped curve implies a behavior that amplifies the income-environmental pollution relationship in the long term [27, 28].

The Brundtland curve hypothesis follows the opposite trend (a U-shaped curve) than the EKC-curve, where environmental damage decreases as GDP/capita increases up to a point where the trend is reversed, following to an increase of the environmental damage. In both theories, Brundtland and EKC, there is a turning point, after which the slope is inversed. Moreover, there is a theoretical explanation as to why the curve rises or falls. The mechanism explaining the increase of the environmental damage is the same for both theories, namely the scale effect. However, the mechanisms explaining its decrease are different. For the EKC theory, this occurs at later stages, when the economies have grown, due to international trade, increased demand for a cleaner environment and more effective production. For the Brundtland curve hypothesis, this occurs at the early stage, where reduced poverty could favor the protection of the environment.

The Daly theory predicts that, the environmental damage increases exponentially with the increase of GDP/capita (does not include any type of turning point). The only solution to save the environment would be to adopt a different type of economy, where growth should not increase steadily but held constant (steady-state economy). The scale effect is also responsible for the increase in the environmental damage and is the common denominator for the three most acknowledged theories on the subject.

3 Production- and Consumption-based emissions

Empirical studies are generally in good agreement with the EKC-type income-elasticity for different water and air pollutants [56, 76, 77]. For other local pollutants though, like carbon monoxide (CO) and volatile organic compound (VOC), is weaker [56]. Global pollutants, like CO₂, are scarcely correlated with the EKC-curve, since time-series and panel data analyses cover only the developed countries [38, 49, 52]. Various studies, that have not been successful finding an EKC correlation for carbon emissions, apply polynomial specifications. Therefore, many studies have tried to find other specifications that validate the hypothesis that economic growth can be correlated with less environmental degradation. Among these studies, spline regression was utilized to test the existence of an inverse-U correlation between GDP/capita and territorial-based CO₂

emissions for a large panel of countries partially with success [78]. Another study utilized nonparametric tests and specifications to panel data. They reported, that a positive monotonic correlation could be valid and rejected the polynomial specification, when controlling for exogeneity of GDP/capita [79]. Smooth transition or threshold models were also utilized by various studies, when estimating the correlation between GDP/capita and CO₂ emissions. The former was used with a panel of developing countries, which resulted to two regimes with positive income elasticities. Over the transition from the first to the second regime, income-elasticity becomes flatter as income grows [68]. In another study, a time-series threshold error-correction model for CO₂ emissions and GDP/capita was suggested. A long-run EKC was validated, when pollution increases relative to the EKC in the short run [80].

A possible solution to the problem of the responsibility of emissions could be the calculation of comparable inventories of carbon emissions based on both territorial-based production and on final consumption [2, 81]. According to these datasets, carbon emissions are concentrated mainly in few developed countries. Recently though, strongly growing developing countries have increased significantly their share of total emissions. Emissions associated with consumption are larger than emissions embodied in the production activities of developed countries [2]. One study found that the regression of GDP/capita and carbon emissions using cross-sectional data, was better consumption rather than for production. Hence, by considering emissions associated in trade, it is confirmed that economic growth relies on CO₂ emissions, and that there is a trade-off in developed countries between economic and pollution goals [82]. On the other hand, the Kyoto protocol, promotes the internalization of the cost of emissions, focusing on its geographic origin. However, one study showed, that this resulted to a decrease of the emissions produced in a country but an increase of the emissions associated with imports, and therefore no significant effects could be observed on overall consumption inventories [81].

One study found the presence of a relative decouple between carbon emissions and economic growth. They calculated the income-elasticity of CO₂ emissions, from both production and consumption, to be less than one. Production-based CO₂ emissions were found to possess smaller income-elasticity than the latter, suggesting that consumption patterns pollute more than production (territorial-based) patterns. Additionally, both inventories possess a threshold specification. When going from a low- to a high-income

regime the elasticity of CO₂ emissions with respect to income reflects some efficiency gains. These findings highlight, that territorial analysis might be ineffective, when emission reduction commitments are aiming local production methods in some developed countries[35].

In Figure 9, a comparison of the production-based and consumption-based emissions of three developed and three developing countries is illustrated for the period from 1990 to 2014. For the developed countries, Germany, United Kingdom and the United States, the consumption-based emissions are higher than the production-based emissions, whereas the opposite is true for the developing countries, Brazil, China and India. The latter three exhibit a monotonically increasing trend for both cases, whereas the developed countries do not. More particularly, Germany and United Kingdom show a downward trend of pollution over time. However, the United States show an inverted-U shape with the turning-point at around 2005[83].

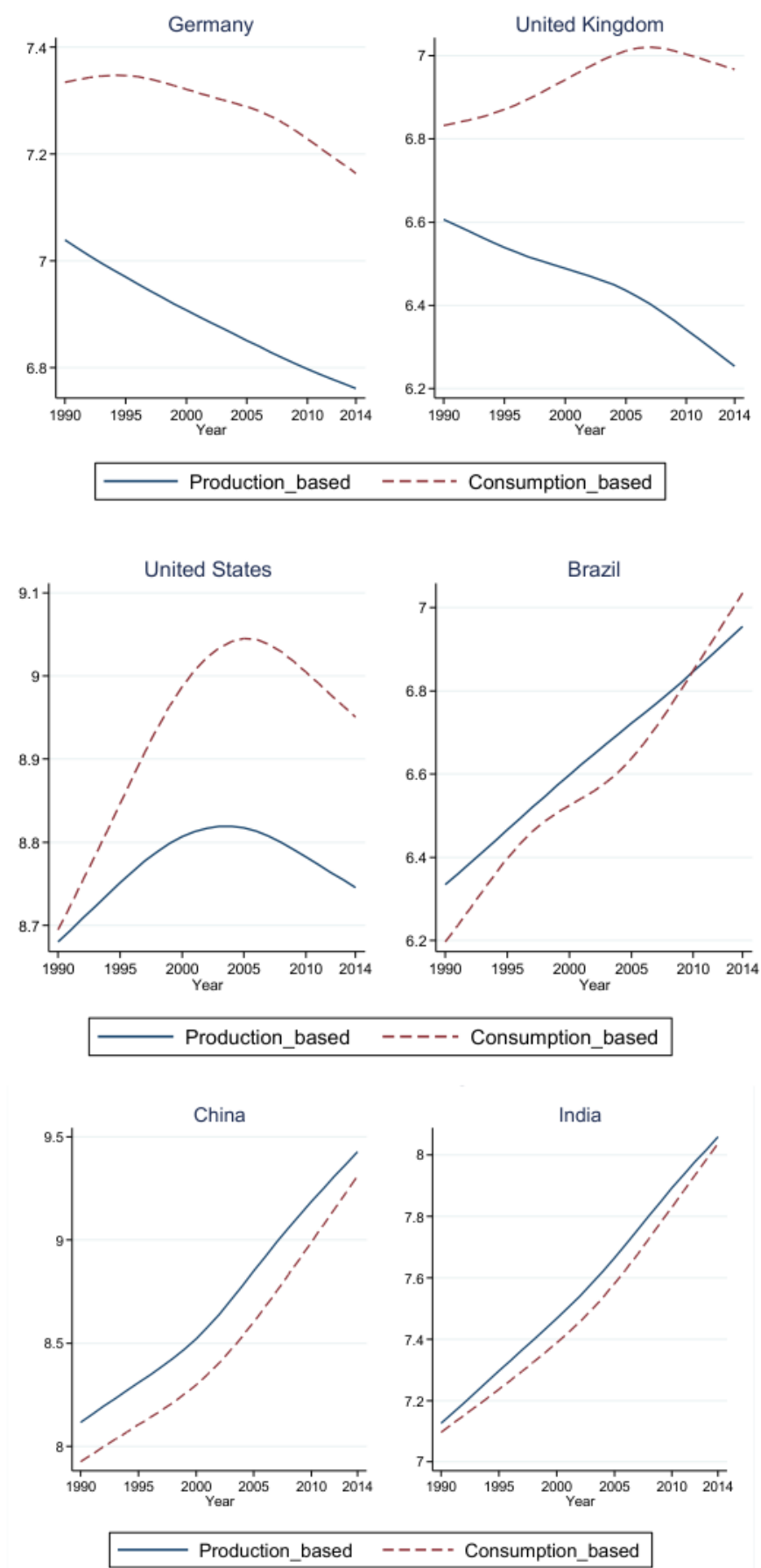


Figure 9: Comparison of production- and consumption-based emissions from 1990 to 2014[83].

In Figure 10 the trend elasticities for 20 countries is presented. The average elasticities for 14 countries were significantly positive, with an average value of 0.4, while only for Saudi Arabia the value was higher than 1 [83]. For the rest of the countries, that is well below unity, a relative decoupling between emissions and output is profound [84]. Developed economies possess elasticities close to 0 and developing economies close to 0.7. For Italy, Russia and Ukraine, income elasticities were found, that were not significantly different from zero and for France, Germany and UK, were found to be significantly negative. These six countries have achieved an absolute decoupling of emissions and output. The former is either stable or decreasing and therefore, they are no longer linked with the increasing trend of output. These countries are considered to be the leaders, in terms of implementing regulations at decarbonizing their economies [85].

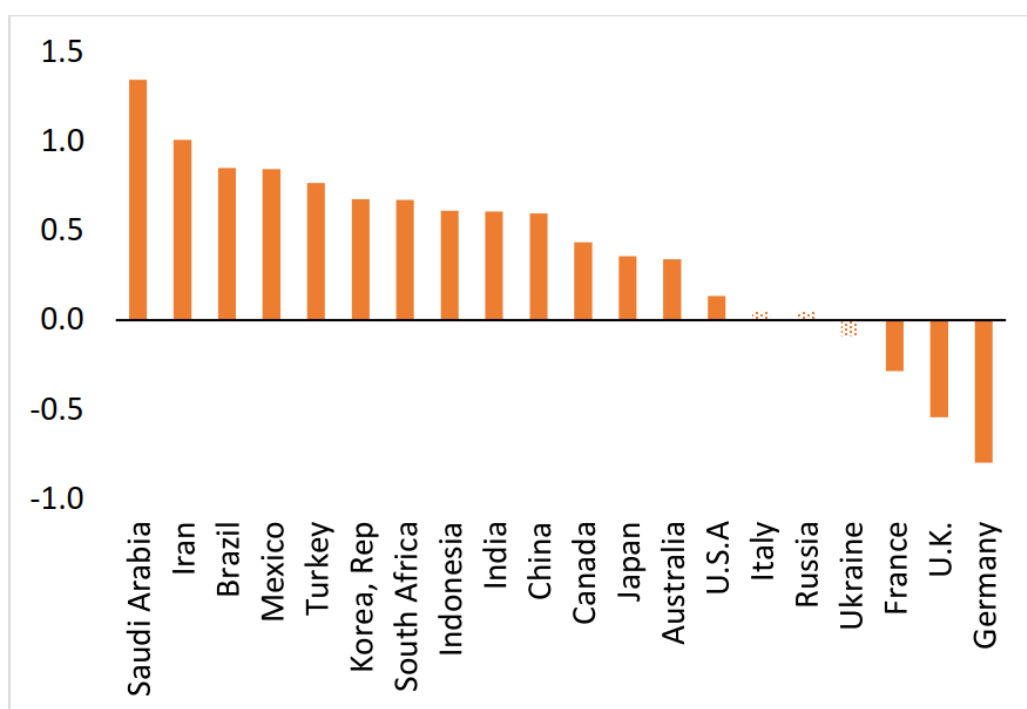


Figure 10: Trend relationship between production-based emissions and output. Each bar represents the trend elasticity estimate resulting from country-specific regressions. Dark shaded orange bars denote statistically significant elasticities estimates at the 10 % level or better, while light shaded orange bars denote statistically insignificant elasticities estimates [83].

Focusing on the production-based and consumption-based trend elasticities for 20 country, the results from a study are presented in Figure 11. International trade has helped developed countries significantly to maintain their consumption patterns, that are carbon-intensive, by importing goods and services that are more polluting than their exports. By comparing the consumption-based trend elasticities, this can be better examined. The average consumption-based trend elasticity is 0.6, whereas the production-

based elasticity has a lower value at 0.4. Developed countries possessed an average production-based elasticity at 0.5, while for developing countries possessed values at approximately 0.7. For the case of Germany, that exhibited the biggest difference between consumption- and production-based elasticity, it was found that the former was at -0.4 and the latter at -0.8 [83].

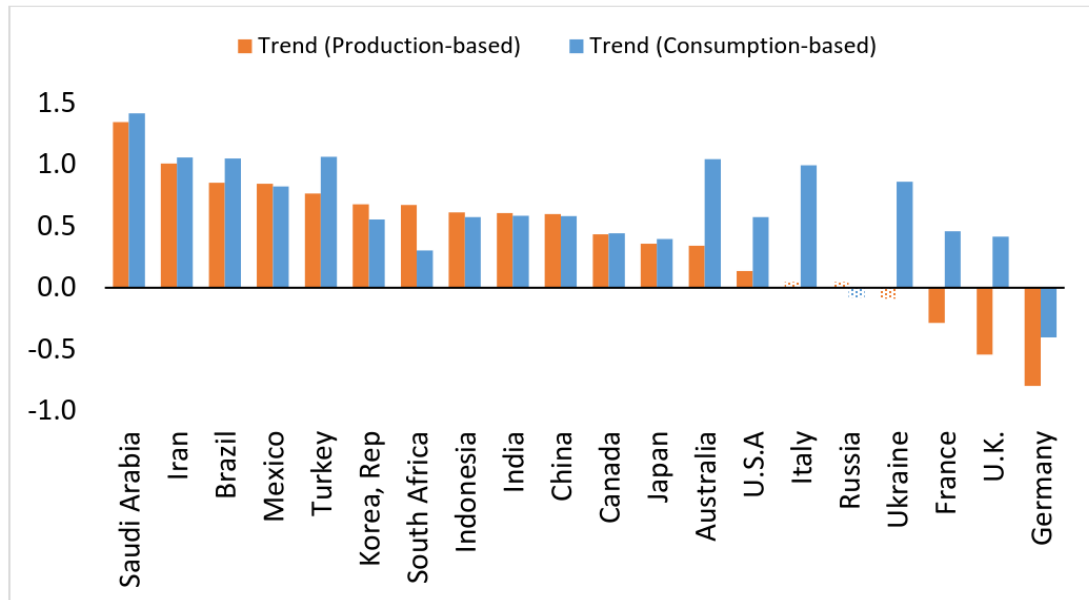


Figure 11: Comparison of production- and consumption-based trend elasticities. Each bar represents the coefficient estimate resulting from countr-specific regressions using either production-based (orange) or consumption-based (blue) emissions as the dependent variable. Dark shaded colors denote statistically significant elasticity estimates at the 10 % level or better, while light shaded colors denote statistically insignificant elasticity estimates [83].

3.1 Concluding remarks and summary

In this chapter, a possible solution to the problem of the responsibility of emissions is discussed, namely the comparison of carbon emissions based on both territorial-based production and on final consumption [2, 81]. It is suggested, that carbon emissions are concentrated mainly in few developed countries. Recently though, strongly growing developing countries have increased significantly their share of total emissions. Emissions associated with consumption are larger than emissions embodied in the production activities of developed countries [2]. Data from the period between 1990 and 2014, indicated that in developed countries, like Germany, United Kingdom and the United States, the consumption-based emissions are higher than the production-based emissions, whereas the opposite is true for the developing countries, like Brazil, China and India. Further, they argue that International trade has helped developed countries significantly to

maintain their consumption patterns, that are carbon-intensive, by importing goods and services that are more polluting than their exports [83].

4 Geographical analysis

In this chapter a geographical analysis takes place. Numerous studies based on empirical data for different countries worldwide are presented in a concise way to give an overview. In some cases, the EKC-pattern is verified, whereas in other cases the pollution levels keep increasing monotonically as economies grow bigger. Here the regions of Europe, Asia, Middle East, the Americas and Africa are reviewed.

4.1 Europe

One study examined the causal relationship of economic growth, energy and CO₂ emissions of Greece and Bulgaria during 1980 and 2010 with the Vector Error Correlation Model (VECM). They reported, that energy, CO₂ emissions, capital and trade openness have a positive relation to growth in the long run for both countries. For the short run, no correlation was found from energy to economic growth for both countries. They suggest, that energy use does not affect CO₂ emissions and economic growth contributes to emissions. That means, that in the short run, emissions could be decreased at the cost of economic growth. On the other hand, greater growth could be achieved by condensing CO₂ emissions in the long run. They conclude and recommend, that both countries should decrease the influence of the government in the energy sector in order to increase efficiency and establish a more flexible economy. Greece should also utilize its solar and wind energy potential according to the European Commission instructions concerning utilization of renewable energy sources [34].

A study for the case of Italy for a 150-year span, from 1861 to 2011, utilized different statistical techniques and suggested that there is a strong non-linear correlation between CO₂ emissions and economic growth. Initially, they are proportionally correlated until the middle of the 1970s. After that, possibly due to the oil crisis and the subsequent regulations in national and international level, emissions were decreased. According to an MR-STAR analysis, a structural shock might have taken place during this period of time, indicating possibly fewer increasing emissions. The EKC-analysis exhibited a bell-shaped correlation between the income and the emissions, with a turning-point pessimistically high [86]. In another study, time-series data were examined for the case of Portugal from 1970 to 2010. They implemented various methods of analysis, among

them OLS and Generalized Method of Moments (GMM) exhibited positive correlation between energy consumption and economic growth. Considering the VEC model, lagged energy consumption was found to be decreasing with increasing economy, reinforcing the use of renewable energy. Overall, globalization and renewable energy are proportionally with economic growth. They concluded that globalization and renewable energy is a driving force promoting environmental regulations [87].

In another study, the long run equilibrium relationship between economic growth, CO₂ emissions and energy consumption for European countries, categorized into middle-level (Germany, Ireland, UK, Belgium, Austria, Spain and France) and high-level knowledge countries (Sweden, Finland, Denmark and Netherlands), according to the Knowledge Economy Index (KEI) 2012 ranking. The sample data were from 1960 to 2012. The EKC-hypothesis was found to be valid for all the above-mentioned countries. For Belgium, France, Denmark, Germany and the UK the falling branch of the EKC-curve is longer or has the same length with the rising branch. This implies an absolute decoupling of emissions and economic growth. This can be seen in Figure 12 among with the turning points for each country. However, for Finland, the Netherlands and Austria, the falling branch is shorter and more flattened than the rising one. This implies that there is a weak evidence, of emissions and economic growth decouple. Stricter regulations and technological innovations should be implemented in order to promote further economic growth with less environmental impact. Additionally, these countries are either characterized by a decrease of energy intensity or a diversified mix of energy consumption, where solid fossil fuels decrease to give rise to nuclear and renewable energy [88].

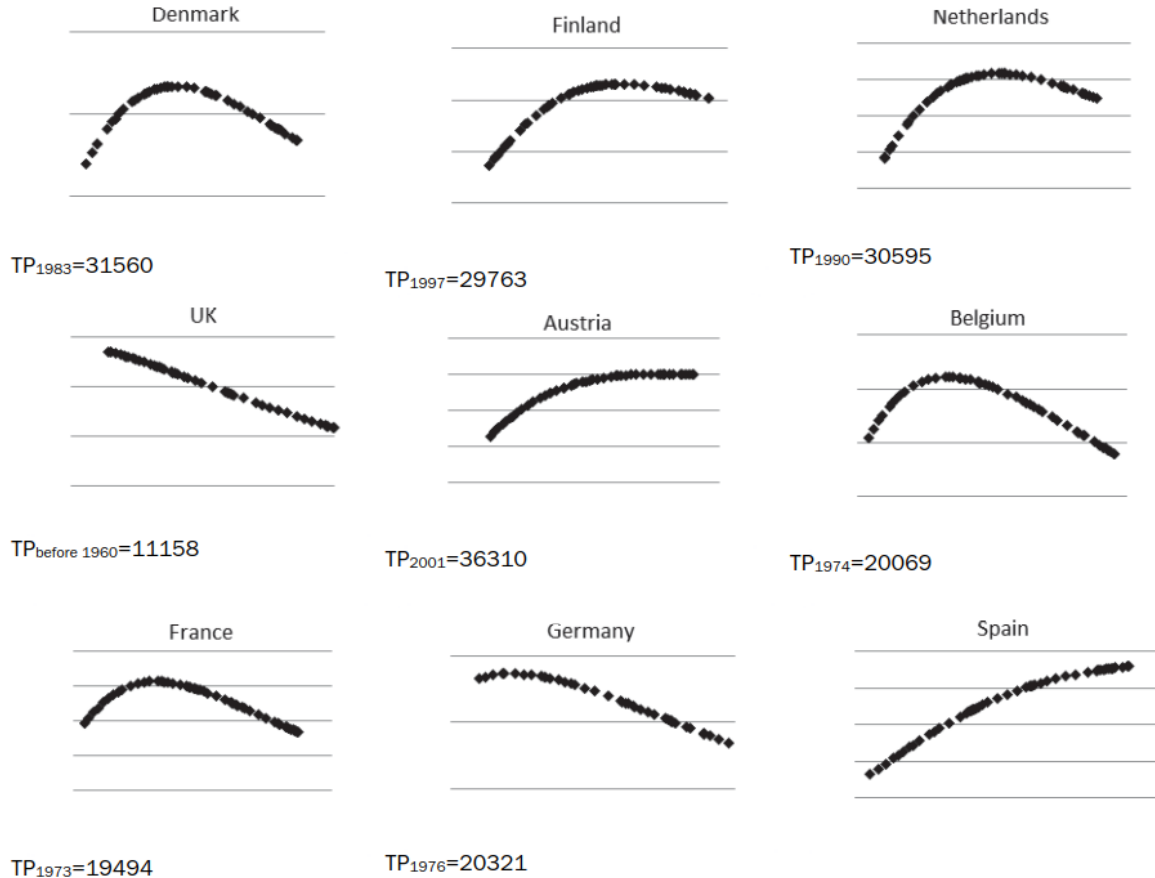


Figure 12: Fitted values of CO₂ emissions/capita over GDP/capita – TP: Turning Point[88].

Data from European countries were also examined before and after the world financial crisis for the periods 2004-2008 and 2008-2012. CO₂ emissions in Germany, France, Spain and the United Kingdom declined in both economic growth and economic crisis. The decline of CO₂ emissions during the crisis was twofold greater than the one during growth, implying that the economic slowdown contributed to the protection of environment. Energy intensity was identified as a key factor towards this reduction of emissions before the crisis but it deteriorated after the crisis during the period from 2008 to 2012. This was attributed to the shift of focus from maintaining and increasing energy efficiency to maintaining economic activities. Economic activities were reduced inevitably during the crisis and this led to a windfall gain in decreasing CO₂ levels, that was not a result of any policies implemented. Concerning energy efficiency, it is achieved in Germany and the UK mainly through technical advancements in a much greater extent rather than in Spain and France. The shift from production to services could also decrease emission levels but to a lesser extent than through technological advancements. They also conducted a what-if analysis in order to demonstrate the opportunities present

from learning from one another through successful experiences of each country, including additional improvements in energy intensity, energy mix and CO₂ carbon emissions. They reported a potential decrease of 16 % of CO₂ emissions compared to the 2012 levels, for the sample countries as a whole. They suggest, that the shift towards carbon-free energy sources, like renewables, is the most effective way to reduce CO₂ emissions, with a 69 % of overall saving, without compromising economic activities [crisis EU].

4.2 Asia

A study considered 4 south Asian countries and found that a long-run correlation is present between income and CO₂ emissions. The income elasticity ranges from 0.94 to 1.84 for Sri Lanka and Bangladesh, respectively. This clearly contradicts the EKC-hypothesis. On the other hand, the results from 6 east Asian countries were in line with the EKC-hypothesis. For all 6 countries, the income elasticity of long run is greater than the one of short run. Exemplarily, for the case of China it increased from 0.36 in the short run to 0.50 in the long run. For Indonesia and Malaysia income elasticity increased from 0.46 to 1.22 and from 0.45 to 1.12, respectively. For Philippines and Thailand, it increased from 1.03 to 1.73 and from 0.78 to 1.52, respectively[89]. For the case of Bangladesh, which is a developing country, data from the period of 1972 to 2010 were examined and the EKC-hypothesis could not be verified. CO₂ emissions were found to increase continuously with economic growth. This was attributed to the lack of structural changes, environmental awareness and environmental regulations. Moreover, international cooperation is considered to be key, as CO₂ is a global pollutant and is not restricted to country borders [90].

Another study for the case of India, examined the correlation between energy consumption, CO₂ emissions and economic growth from 1976 to 2006. They reported that CO₂ emissions affect positively the energy use and capital but negatively the GDP and population. On the other hand, energy consumption affects positively the CO₂ emissions and the GDP but negatively the population and the capital. This suggests, that capital and population, namely labor, have been replaced to a great extent by energy use in the production processes. Energy consumption is a driving force for economic growth and in order to maintain growth, alternative non-polluting technologies should be researched and adopted for energy production [91]. Time-series data from 1971 to 2006 were examined for the case of Pakistan. The authors of the study reported that CO₂ emissions

increased monotonically with the increase of the economic growth and thus, the EKC was not verified. They explained the reasons for this correlation to be; i) lack of environmental regulations and ii) lack of political willingness to implement new stricter environmental regulations. Politicians in Pakistan seem to believe that these new regulations would inevitably lead to high amount of spendings. Pakistan's economy is mainly based on agriculture with almost 54 % of the total energy consumption depends on oil and gas, contributing heavily to CO₂ emissions[92].

China has also been studied by many authors. Data for the period from 1985 to 2005 were examined in terms of GDP/capita and i) waste gas, ii) waste water and iii) solid wastes. All three pollutants follow the EKC-pattern and have a long-run co-integration correlation with GDP/capita. The results can be seen in Figure 13. It is also observed, that waste water was the first pollutant decreased compared to the other two. This is attributed to the relevant regulations in national level. Only few well-developed regions have reached the turning-point and have started decreasing pollution. This especially true for waste gas and solid wastes[93].

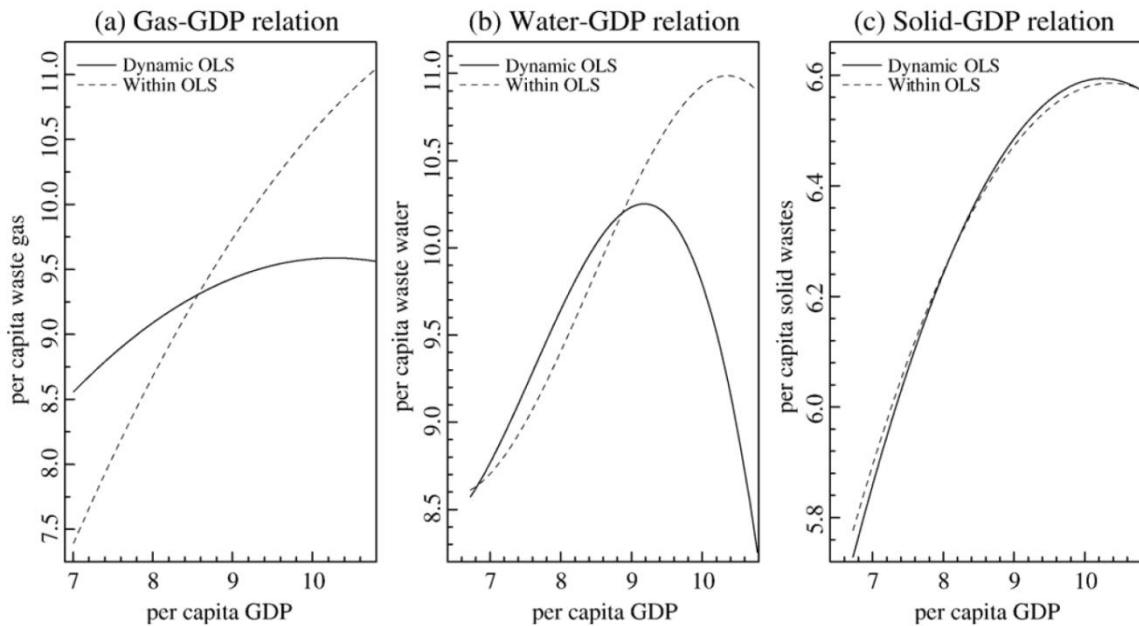


Figure 13: Pollution-income relationships for a) waste gas, b) waste water and c) solid wastes from the Dynamic OLS and within OLS estimators[93].

Additional data for China for the period from 2000 to 2015, focusing on the air quality index, were analyzed with two improved EKC-models, a two-square EKC and a three-square EKC model. Co-integration analysis under the three-square model exhibited that the air quality index and the GDP/capita follow the N-shaped curve, whereas the two-

square model resulted to a U-shaped relationship between the aforementioned variables. The results imply, that initially the trend between emissions and GDP/capita are opposite for the two models but in the long run they follow the same trend, namely with an increasing economy, emissions would also increase [94].

For the case of Vietnam, data from 1980 to 2010 were examined and showed that the EKC-hypothesis is not supported. Among energy consumption, CO₂ emissions and economic growth they also took under consideration the Foreign Direct Investments (FDI) inflows. The bi-directional correlation between income and FDI inflows, suggests that income increase will attract foreign investments in the short run. And vice versa, higher FDI inflows would promote economic growth. In the long run a bi-directional causality between FDI inflows and energy consumption was found and a uni-directional causality of CO₂ emissions and FDI inflows. This suggests, that these factors are strongly correlated, and that energy consumption would increase with increasing FDI in host countries. This supports the pollution haven hypothesis. More loose environmental regulations would attract more FDI inflows, which would increase the levels of pollution[95]. Data of Singapore, Korea, Taiwan and Hong Kong from 1990 to 2012 were also examined with the FMOLS method. They report a strong correlation between energy consumption and greenhouse gases emissions. A 1 % increase in the former leads to a 0.18 % increase of greenhouse gas emissions. Further, a statistically significant non-linear correlation between emissions and economic growth was found. In terms of causality, a short term uni-directional relationship between energy consumption and emissions was found and a bi-directional causality emissions and economic growth with feedback mechanisms. A long-term relationship a strong uni-directional causality from economic growth and energy consumption to emissions was observed [96].

4.3 Middle East

One study examined the EKC-pattern for 12 middle eastern countries. They found that in the short-run income has a positive and statistically significant effect on CO₂ emissions in Kuwait, Iraq, Jordan, Qatar and Saudi Arabia. On the other hand, the results from Yemen showed, the opposite trend, where a 1 % increase in income resulted to a decrease of CO₂ emissions by approximately 2.5 %. The short-run income elasticity for Iraq and Saudi Arabia ranges at 0.33 and 0.40, respectively. In Kuwait it is >1. In the long run, 1 % increase of income resulted to decrease of CO₂ emissions by 0.1 % and

2.2 % for Iraq and Yemen, respectively. This verifies the EKC hypothesis. Another way to examine this, namely whether or not further increase of income leads to reduction of CO₂ emissions is to compare the long-run impact of economic growth on emissions with the short-run impact. If the long-run income-elasticity is smaller than the short-run, then as the economy grows the emissions decrease. This seems to be true for Kuwait, Qatar and Jordan. For the case of the UAE, for both short- and long-runs the effect of income on emissions is statistically insignificant [89].

In another study with data ranging from 1990 to 2011, it was found that the energy consumption affects positively and to a great extent the GDP/capita for Oman, Qatar, UAE, Iran and Bahrain but the effect was found to be insignificant for Jordan and Syria. For Egypt and Lebanon, it was found to follow a negative trend, meaning that an increase in energy consumption would lead to decrease of economic growth. As per pollutant variable, CO₂ emissions affect negatively the GDP/capita for all the above-mentioned countries, except Jordan and Syria. These two countries exhibited an insignificant negative correlation. Moreover, they reported a negative impact of labor force on GDP/capita. They attributed it to brain-drain and to the potentially low productivity of labor force, due to lack of skills. Labor tends to reduce the GDP/capita more than emissions, which might be due to the fact that, in developing countries labor is potentially more abundant and cheaper than in the developed ones [97]. Furthermore, they considered the variables of urbanization and life expectancy[98]. Urbanization is defined as the percentage of the urban population based on the overall population. This is an important determinant of the environment quality, since the increase of population density in urban areas, results to an increase in food needs, leading to an over-exploitation of natural resources and increase of CO₂ emissions[79]. Life expectancy is defined as the number of years a newborn infant would live in average, if prevailing patterns of mortality at the time of its birth, were to stay unchanged. Life expectancy depends heavily among others on the environmental quality and wellbeing of the population. It has been shown that environmental degradation is directly correlated to health problems, like respiratory diseases, nutritional deficiencies, and certain types of cancer[98]. In the short run, life expectancy exhibited no significant effect on CO₂ emissions for Iran, Bahrain, Syria, Qatar, Oman and UAE. For Jordan, on the other hand, a negative effect at 10 % was found on the CO₂ emissions. This suggests that an increase in life expectancy is feasible only at the expense of increasing emissions. Regarding the urbanization effect, they only found a positive and significant correlation at 5 % for Jordan and Qatar. In the long run, life ex-

pectancy a negative and significant impact on emissions at 1 % for Jordan, 5 % for Qatar and Yemen and 10 % for Saudi Arabia. However, Egypt exhibited a positive and significant correlation at 1 %. Increase of life expectancy by 1 unit would require increase of CO₂ emissions by 2.0126 units. This was attributed to the fact that, increase of life quality should be achieved by the consumption of polluting energy goods. In terms of urbanization, a negative and significant relationship was found at 1 % for Egypt, and a positive and significant effect at 1 % for Jordan, 5 % for Qatar and 10 % for Saudi Arabia. A priori, with increase of population density in urban areas, more goods and services, like transportation, are consumed, which contribute significantly to CO₂ emissions [98].

4.4 The Americas

For the case of Argentina, a 1 % increase in income resulted to an increase of CO₂ emissions by 0.55 % and 0.44 % in the short and long run, respectively. In Mexico the income-elasticity was found to be 0.60 and 0.43 in the short and long run, respectively. Income elasticity was statistically insignificant for the case of Colombia for both short and long run. In Venezuela it was found to be insignificant only in the long run [89].

In a study for the case of the USA, data from 1981 to 2003 were examined using a dynamic ordinary least squares model. They verified the EKC-hypothesis [99]. These findings are also in line with other authors [100]. Moreover, they decomposed the CO₂ emissions into the factors of population, economic and technological growth. In Figure 14 it is shown, that the energy-related CO₂ emissions have been increasing steadily since 1981. The variables C, Q and P denote CO₂ emissions, income and population, respectively. Accordingly, Q/P income per capita and C/Q CO₂ emissions per income. The trend is steadily upwards with a clear seasonal influence on CO₂ emissions, due to the fact that emissions are estimated based upon energy consumption, which is one of the main contributors to national emissions and is characterized by seasonality. This increasing trend is leveling though. This implies that an economic stimulus policy could effectively decrease CO₂ emissions. Therefore, conservation policies should be coupled with economic stimulus policies to mitigate emissions as a whole. This means, that income depicted as GDP might not be sufficient in and of itself to relieve the pressure of emissions [99].

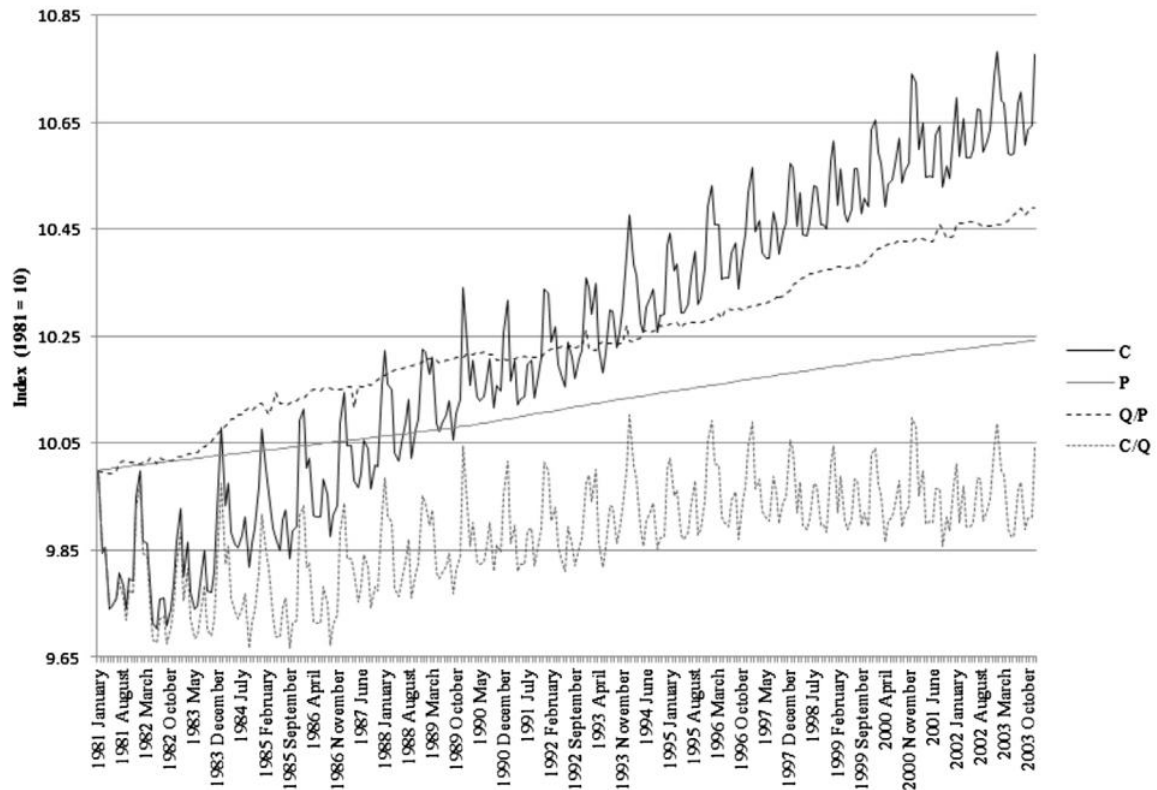


Figure 14: IPAT decomposition [99].

Another study examined empirical data for Canada covering a period of 57 years, from 1948 to 2005. They found no evidence of the EKC-pattern. Instead, they reported that CO₂ emissions increase monotonically with economic growth but with a non-constant slope. In their analysis, they assumed that only GDP/capita is non-linearly correlated with CO₂ emissions/capita. By doing so, they were able to observe changes of the relationship, at the time the oil crisis in the 1970s occurred, between CO₂ emissions/capita and time, but also between CO₂ emissions/capita and GDP/capita [101].

4.5 Africa

Within a sample of 12 countries in the African continent, Algeria, Ethiopia, Nigeria and Kenya possessed a statistically insignificant income elasticity in the long run. For Ghana and South Africa, it has decreased from 1.32 to 1.21 and from 0.75 to 0.49, from short term to long term respectively. Congo exhibited negative values for both short and long run, suggesting that economic growth lead to reduction of emissions [89]. In Mauritius, income elasticity has been increasing steadily over time for the period from 1975 to 2008. The EKC-pattern could not be verified, namely human activities increasingly

impact the environment. Mauritius' dependency on imported fossil fuels, for energy generation, is approximately at 82 % and is increasing. Virtually, all energy is consumed in the form of electricity or as liquid in transportation and correspond to 81 % of the total CO₂ emissions of the country [102].

In another study for Ethiopia, time-series data from 1970 to 2010 were examined. The findings show that the energy consumption increases proportionally with economic growth both in the short- and the long-term but CO₂ emissions are decoupled from economic growth in the long-term. This was achieved due to the utilization of hydrodynamic and geothermal energy, that helped Ethiopia to grow a green economy[103]. In a similar analysis for Nigeria from 1971 to 2009, a positive relationship among the variables was found. With increasing economic growth, energy consumption was increasing and in turn CO₂ emissions were also increasing. This reveals the poor nature of electricity supply in Nigeria. They suggest a holistic approach on the planning of the investments in the energy infrastructures to decouple CO₂ emissions from economic growth in the long run [104].

It is also reported, that the GDP/capita affects positively and to a great extent the pollution levels in long-run in Ivory Coast. However, in the short-term no significant influence was found between income and variation of emissions. Causality tests indicated that there is no correlation between income and CO₂ emissions. Because of the fact that, the production processes are rather old, in terms of technology, the variation of the pollution levels were mainly because of the energy consumption and not the production level. Further, the causality analysis supported the growth hypothesis in Botswana and Kenya, and therefore energy consumption was identified as a critical production factor. Trade openness was also considered and its effect on emissions was found to be negative for South Africa. South Africa, Kenya and Togo cannot benefit from international trade, since their integration rate in the world trade is not sufficient. This means that they export mainly natural resources and import manufactured goods. Subsequently, fluctuations in commodity prices could hinder the country's ability to purchase new efficient technologies with priority given to basic necessities and therefore promoting heavy-polluting industries [105].

4.6 Concluding remarks and summary

For European countries, data from 1960 to 2012 were examined. For Belgium, France, Denmark, Germany and the UK an absolute decoupling of emissions and economic growth was found, mainly due to the rise of the share of nuclear energy in the energy mix. However, for Finland, the Netherlands and Austria, there is a weak evidence, of emissions and economic growth decouple [88].

For the continent of Asia, studies about India, for the period from 1976 to 2006, reported that CO₂ emissions affect positively the energy use and capital but negatively the GDP and population. On the other hand, energy consumption affects positively the CO₂ emissions and the GDP but negatively the population and the capital. This suggests, that capital and population, namely labor, have been replaced to a great extent by energy use in the production processes. For the case of China, for the period from 1985 to 2005 waste gas, waste water and solid wastes were examined. All three pollutants follow the EKC-pattern and have a long-run co-integration correlation with GDP/capita [93]. Additional data for China for the period from 2000 to 2015, focusing on the air quality index, were analyzed with different improved EKC-models. Co-integration analysis under the three-square model exhibited that the air quality index and the GDP/capita follow the N-shaped curve, whereas the two-square model resulted to a U-shaped relationship between the aforementioned variables.

Concerning the middle eastern countries, it was found that in the short-run income has a positive and statistically significant effect on CO₂ emissions in Kuwait, Iraq, Jordan, Qatar and Saudi Arabia[89]. Furthermore, the variables of urbanization and life expectancy were also considered [98]. Urbanization is an important determinant of the environment quality, since the increase of population density in urban areas, results to an increase in food needs, leading to an over-exploitation of natural resources and increase of CO₂ emissions[79]. Life expectancy depends heavily among others on the environmental quality and wellbeing of the population [98]. In the short run, life expectancy exhibited no significant effect on CO₂ emissions for Iran, Bahrain, Syria, Qatar, Oman and UAE. For Jordan, on the other hand, a negative effect at 10 % was found on the CO₂ emissions. This suggests that an increase in life expectancy is feasible only at the expense of increasing emissions. An increase of life expectancy in Egypt by 1 unit would require an increase of CO₂ emissions by 2.0126 units. This was attributed to the

fact that, increase of life quality should be achieved by the consumption of polluting energy goods [98].

For the case of the USA, the EKC-hypothesis was verified. By decomposing the CO₂ emissions into the factors of population, economic and technological growth, they found that the trend is steadily upwards with a clear seasonal influence on CO₂ emissions, due to the fact that emissions are estimated based upon energy consumption, which is one of the main contributors to national emissions and is characterized by seasonality [99].

Focusing on the continent of Africa, Congo exhibited economic growth while reducing CO₂ emissions [89]. However, in Mauritius, the EKC-pattern could not be verified, namely human activities increasingly impact the environment. Trade openness and its effect on emissions were also considered. South Africa, Kenya and Togo cannot benefit from international trade, since their integration rate in the world trade is not sufficient. This means that they export mainly natural resources and import manufactured goods [105].

5 Energy mix and renewable energy sources

In this chapter the energy mix and CO₂ emissions in a global level are discussed. The analysis includes the changes in annual CO₂ emissions deriving from fossil fuels, cement clinker production processes, the largest source of non-combustion-related CO₂ emissions), and from nuclear energy. The contribution of all the major-polluting countries is discussed as well as the trend by introducing renewable energy sources in the energy mix.

5.1 Global CO₂ emissions

In 2011, the global CO₂ emissions reached an all-time record of 34 billion tonnes. This is depicted in Figure 15. Emissions from China and the USA account to 29 % and 16 % of the global CO₂ levels, respectively. European Union (EU27) and India contribute by 11 % and 6 %, respectively. The lowest contribution was found for Russian Federation at 5 % and Japan by 4 %. A detailed comparison of each country's contribution can be found in Figure 16[36].

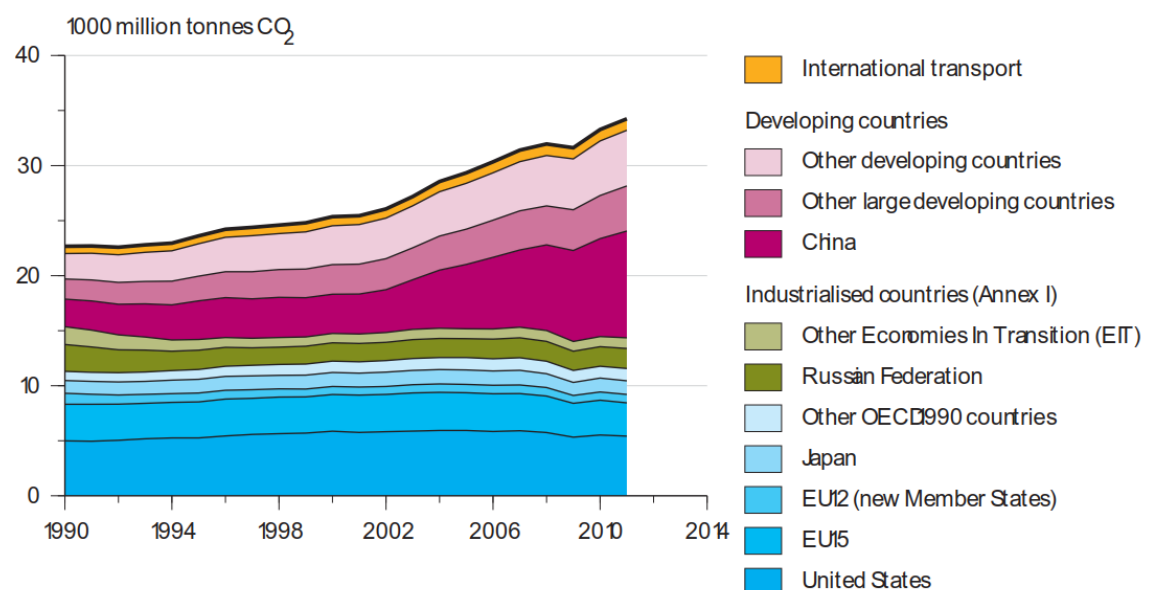


Figure 15: Global CO₂ emissions per region from cement production and fossil fuels [36].

During the period between 2000 and 2011 average annual emissions were increasing steadily by up to 3 %. This was not expected, as many OECD countries in fact had decreased CO₂ emissions (in the USA and Japan by 2 % and in the EU27 by 3 %), due to the weak economic conditions in many countries, the high oil prices and the relatively mild winter. In the EU27, a decrease of 10 % in natural gas consumption was reported [106]. It is reported that high oil prices resulted to a decrease in fuel consumption. This was especially true for the case of the USA, where average petrol prices increased by 28 % in 2011 [36]. It is also important to note that OECD countries account for only 33 % of global CO₂ emissions. India and China possess the same share and it increased by 6 % and 9 % in 2011, respectively. It is remarkable the fact that, although all developing countries together increased their emissions by an average of 6 %, the increase in China and India was responsible for the by far largest increase in global emissions of 1 billion tonnes in 2011 [36].

Cement production is the largest source of non-combustion-related process that contributes 4 % to the global total CO₂ emissions. Its recent increase by 11 % in China led to a 6 % increase globally. Gas flare is the process of combustion of all waste gases in the chemical and petrochemical industry. It accounts in a much smaller amount of global CO₂ emissions than the cement production. In the USA and Russia, it increased significantly, whereas it decreased in Libya [36].

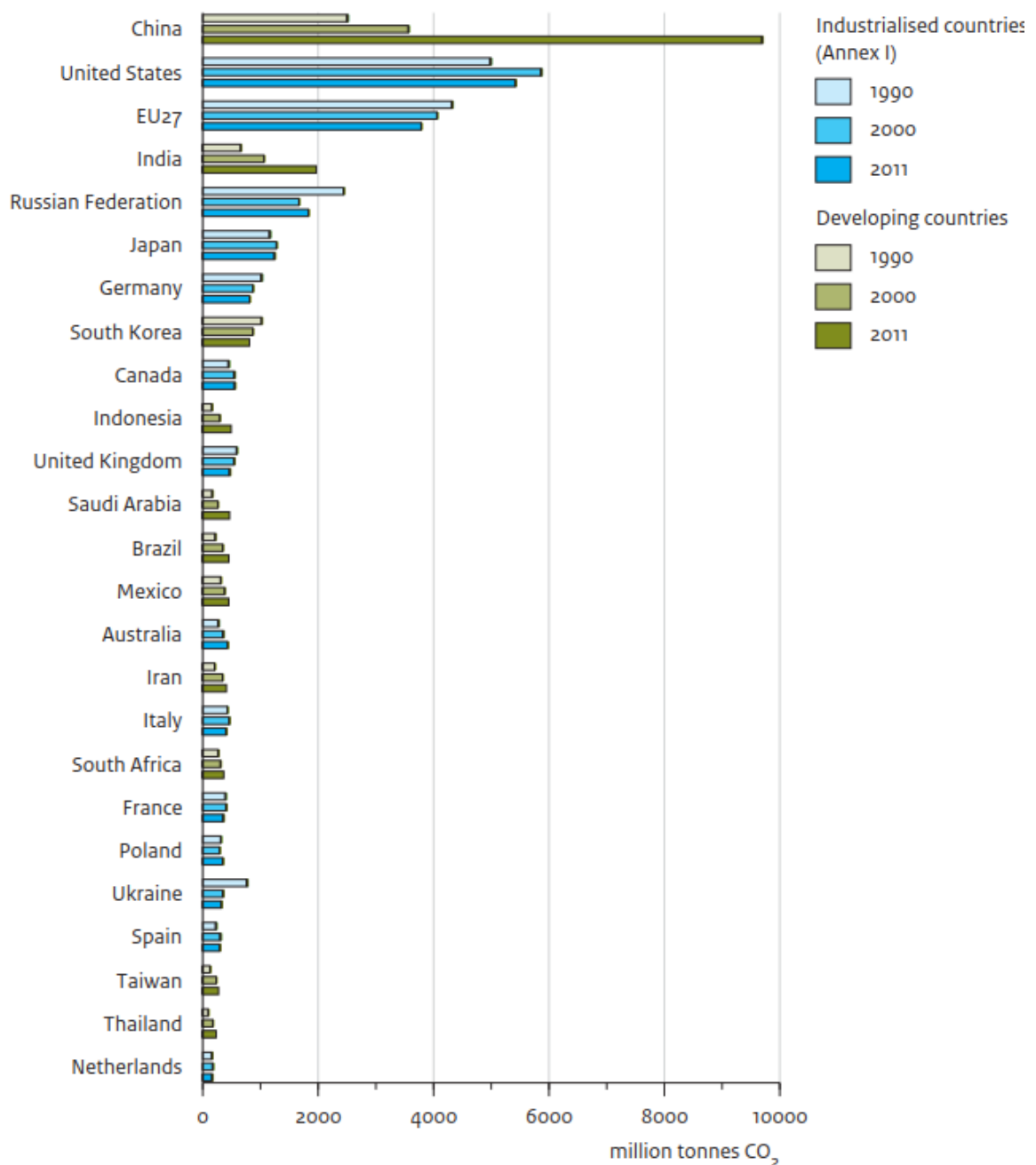


Figure 16: CO₂ emissions per country from fossil fuel and cement production [36].

Total emissions in the EU27 and the USA decreased by 3 % and 2 % in 2011, respectively. The same decrease is reported for Japan. However, Australia, Canada and Russia increased their emissions in 2011 by 8 %, 2 % and 3 %, respectively. In countries with economies in transition (EIT), emissions also increased, such as in Ukraine by 7 %. China and India increased their CO₂ emissions by 150 % and 75 %, respectively. After the world financial crisis in 2008, China has implemented counter-measures to ensure economic growth, unlike other countries. The focus of this measures was to maintain economic growth, to rebuild the Sichuan communities that were destroyed by the 2008

earthquake and also to invest in transport infrastructure. This resulted to an increase of China's emissions by 9 % [36]. This is in line with the increase of thermal power generation of 14.7 %, in steel production of 7.3 % and in cement production of 10.8 % [107].

India was also unaffected by the financial crisis like China but due to different reasons. India's domestic demand makes up 75 % of the national economy. China increased domestic investments in infrastructures to offset the great decrease in the exports/GDP ratio, but India stimulated the already high share of domestic consumption in total national expenditure. India is the fourth largest CO₂ contributor after the EU27 and Russia[36].

5.2 Fossil fuels consumption

Fossil fuels combustion contributes approximately 90 % of the total global CO₂ emissions [3]. Global energy consumption increased together with the global economy by 2.5 %. Global fossil oil consumption increased by 2.9 % in 2011. The oil consumption in China was found to increase by 5.5 % and accounted for 66 % of the growth in trade in 2011, while oil imports increased by 13 %. Concerning the natural gas consumption, it increased globally by 2.2 % in 2011. China, Saudi Arabia and Japan exhibited the highest growth by 22 %, 13 % and 12 %. On the other hand, the EU27 showed the biggest decrease on record with 11 %. This was attributed mainly to the weak economy, high gas prices and continued growth renewable electricity production[36].

For coal consumption, a global increase of 5.4 % was found in 2011. This is an above average increase, and accounts for 30.3 % of the global energy consumption. In China, coal consumption increased by 9.7 %, which accounts for 49 % of global coal consumption. This increase is ratified, by the expansion of infrastructures and building construction, as indicated by the increase of the production in steel and cement. China increased its coal import by 10 %, overtook Japan and was the largest coal importer in 2011 [in SOS1 Reuters 2012d]. The level of coal imports is determined mainly by the price difference between domestic and international coal price [36]. Further analyzing how coal consumption affected CO₂ emissions economic growth, data from the top 10 coal-consuming countries, China, the USA, India, Germany, Russia, South Africa, Japan, Australia, Poland and South Korea, were examined for the period between 1992 to 2009. A long-term correlation between all three variables was found for all the aforementioned countries. However, no causality was found between these variables, but a

positive bi-directional correlation was found between CO₂ emissions and total energy consumption in the short-term. Therefore, energy conservation policies on total consumption would have no negative impact on the real output growth for these countries [108].

5.3 Nuclear and renewable energy sources

Within societies, the organizational and social behavior patterns have been directly influenced by the fluctuating energy sector. For example, rapidly increasing energy demands have accelerated the collapse of fossil fuels. This, together with the volatility and pressure surrounding energy prices, has caused further pollution. The elasticity to legitimize a response to environmental degradation has led to technological improvements, not only in terms of energy and production efficiency but also in discovering new energy sources, that are pollution-free, like renewables or at least CO₂-free, like nuclear energy. This is a fundamental addition to the socioeconomic discussion about positive effects on sustainable development [29].

Incorporation of nuclear energy in the energy mix, is an effective way to reduce CO₂ emissions. The problematic of the nuclear waste disposal will not be discussed in this study, as it is out of scope. It is reported, that Japan was the third biggest producer of nuclear energy after the USA and France, with a share of 29 % in 2010 [36]. After the Fukushima accident though in March 2011, Japan changed significantly its energy mix due to safety considerations, by shutting down 54 nuclear reactors. The lack of 280 TWh was compensated by power cuts and boosted gas-fire power generation [109]. Germany also shut down 8 nuclear reactors with an overall capacity of GWh, after the Fukushima accident. Its 4 % reduction of the share of nuclear energy in the energy mix was compensated by renewables and coal [36]. Photovoltaic energy was increased significantly, contributing 3 % in 2011 to the power generation [36].

Total renewable sources have increased significantly and supply as much as 16.7 % of the global final energy consumption [4]. At least 118 countries, both developing and developed, had set renewable energy targets by early 2012. Renewables in the USA provided 12.7 % of the total domestic electricity in 2011. In Germany, renewables account for 20 % of its total electricity consumption [4]. Concerning the total global wind power capacity, it was 238 GW at the end of 2011. Asia was the biggest investor on wind

power, accounting for 52 % of the total wind power capacity and followed by the EU27 and North America, accounting for 25 % and 20 %, respectively. China is the biggest wind power market, but new installation leveled-off in 2011 for the first time [36]. This was attributed to the fact that the grid remains the most important issue hindering wind development. The grid did not expand as fast as the wind power capacity [109]. In Europe, 6.3 % of the total electricity consumption is covered by wind energy, with Germany being the leader and the UK, Spain, Italy and France following. In the USA, the wind capacity increased by 30 % from 2010 to 2011 [36].

Solar energy showed also a significant increase by 75 % globally in 2011. Solar energy harnessed by photovoltaics (PV) is one of the most important renewables in terms of globally installed capacity after hydropower and wind power. China has doubled its photovoltaic capacity and Europe increased it by 75 % in 2011. Hydropower however, exhibited the smallest increase by 1.6 % globally since 2003. China was leading in hydropower capacity contributing 20 % to the total global hydropower share of energy in 2011. Brazil, Canada, the USA and Russia were following with a share of 12 %, 11 %, 10 % and 5 %, respectively [36]. Concerning biofuel production, it rose only by 0.7 % in 2011 [106]. Consumption of biofuels in the USA slowed down, when the concentration of the bioethanol in the fuel reached the upper limit, for safe usage in the existing internal combustion engines of cars. In the EU, it decreased by 3 % in 2011. Exemplarily, by 14 % in France and 24 % in the UK. Biofuels, both biodiesel and bioethanol, represent approximately 3 % of the global automotive fuels. It would have been expected to lead to a similar reduction of CO₂ emissions, if biofuel had been produced sustainably [36].

New policies and regulations, aiming to increase the share of nuclear and renewable energy sources affected the trends in CO₂ emissions globally. Renewables like solar and wind energy as well as biofuels played an important role in decreasing emissions, although their share is still very small, they are increasing with accelerating speed. Utilization of renewable energy sources combined with energy savings and optimizations would lead to a further decrease of CO₂ emissions [36]. It is estimated that the returns on energy innovation investments are lower than the social benefits, which, without public intervention, would have been difficult to achieve [36]. We can assume that environmental degradation is a negative externality. A negative externality occurs when production and/or consumption causes external costs on third parties outside of the

market, for which no appropriate compensation is paid. This could lead to social costs exceeding private costs. In this scenario, the empirical findings indicate a correlation between low-carbon technological achievements and the decrease of pollution [5, 110]. On the other hand, the positioning of imperfect competition, namely when a market structure is not controlled entirely by market forces, would lead to sectoral diminishing returns. This effect would make it impossible to achieve long-term economic growth without avoiding a certain level of increased pollution [29]. A prerequisite for sustainable growth is the existence of constant returns to scale or growth in pollution removal activities. Therefore, pollution will always continue to grow, unless there is an environmental intervention. If there is no intervention, then the economy is characterized by exogenous growth, namely that it grows only due to factors that exist outside of the given economy [24].

The EKC-model supports the idea that innovation and economic growth can promote environmental corrective measures, where the energy sector is a key factor towards influencing emission levels [5]. After the first stage of the EKC, namely the first turning point, pollution decreases due to energy innovation processes. Once the second turning point is reached and the pollution starts to increase again, the N-shaped relationship describes this behavior. This is illustrated in Figure 17 along with the delay of the scale effect after the second turning point, namely the second increase of pollution as the economy grows, due to energy innovation processes [5].

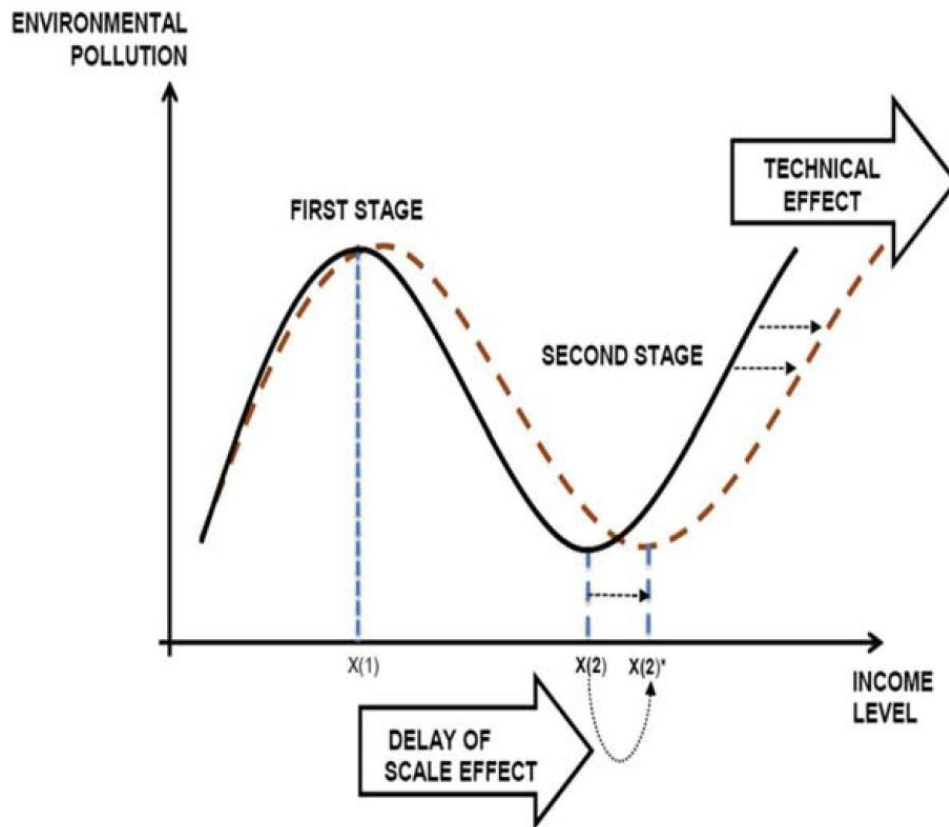


Figure 17: Technical effect in the EKC-model – the N-shaped relationship [29].

Concerning the technical obsolescence, it is reported that it can diminish the long-term positive effect of the innovation achievements [37]. It is suggested that sufficient environmental regulations can significantly promote technological innovations, which suppress the scale effect in the long-term [5, 28]. However, the technical obsolescence, leads to the diminishing returns of the technological change, that promotes pollution reduction. This leads to an increase of pollution according to the N-shaped relationship. When technical obsolescence appears, after the second turning-point, it is an indicator that energy-related regulations are inefficient and/or insufficient. The absence of the latter could lead economies to reach technical obsolescence sooner than in economies with strong regulations [37]. It is necessary to keep striving towards even more and stronger regulations, aiming to energy innovations in terms of both more efficient processes and discovery and utilization of renewable energy sources.

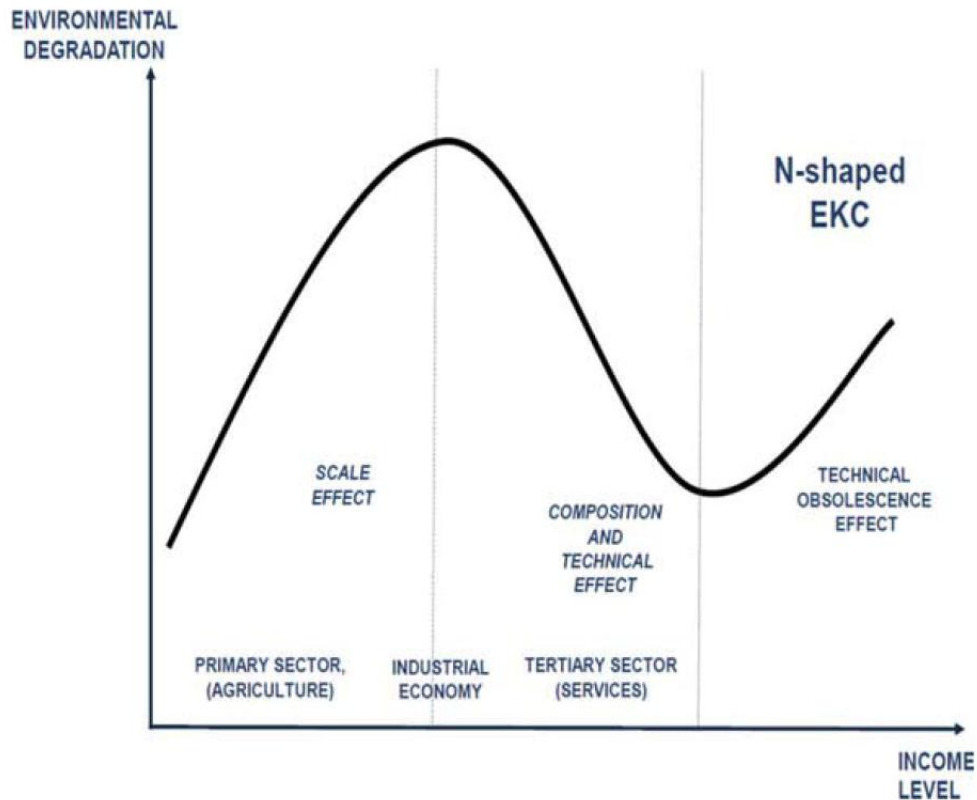


Figure 18: The effect of technical obsolescence in the EKC model [29].

One study examined empirical data for Malaysia for the period 1980 to 2009. They considered the correlation between CO₂ emissions, economic growth and the potential of renewable energy sources and trade openness both in the long- and in the short-run. They found a cointegration relationship among the variables and the EKC-pattern was verified between CO₂ emissions and GDP/capita. They also found, that the elasticity of CO₂ emissions with respect to electricity generation from renewables is negative and statistically significant in both the short- and the long-term [111]. This is in good agreement with the results of another study, that found a negative elasticity between nuclear power and CO₂ emissions [112]. Concerning the elasticity of CO₂ and trade openness, it was found to be negative. With a 1 % increase in foreign trade resulting a 9.5 % decrease in CO₂ emissions/capita in the long-term in Malaysia. Additionally, they reported a bi-directional causality between GDP/capita – emissions and electricity generation – emissions in the long-term. A uni-directional relationship was found for trade openness and CO₂ emissions in the long-term. They indicated the importance of renewables in controlling CO₂ emissions in Malaysia. Renewables would maintain the growth of electricity supply, while at the same time could reduce CO₂ emissions [111].

In another study, empirical data from G7 countries were in terms clean energy consumption, economic growth and CO₂ emissions were examined for the period between 1965 to 2015. They found no cointegration for any variable for Canada, France, the USA, the UK and Italy. However, in Germany there was a cointegration between economic growth and CO₂ emissions. They also reported a uni-directional causality between clean energy consumption and economic growth for Canada, Germany and the USA: A bi-directional relationship between clean energy consumption and CO₂ emissions for Germany but a uni-directional relationship for the USA was found. They suggested, that G7 countries, have to some extent efficient energy-use strategies against CO₂ emissions and that clean energy resources can bridge the gap between economic growth and environmental protection in both G7 and developing countries [113].

5.4 Concluding remarks and summary

In 2011, the global CO₂ emissions reached an all-time record of 34 billion tonnes. China and the USA were the main contributors with levels at 29 % and 16 %, respectively. During the period between 2000 and 2011 average annual emissions were increasing steadily by up to 3 %, which was not expected, due to the weak economic conditions in many countries, the high oil prices and the relatively mild winter. Different sources of CO₂ emissions were identified and discussed. Among them, cement production, the largest source of non-combustion-related process, contributes 4 % to the global total CO₂ emissions [36]. Fossil fuels combustion contributes approximately 90 % of the total global CO₂ emissions [3]. Global fossil oil consumption increased by 2.9 % in 2011. % and natural gas consumption increased globally by 2.2 % in the same year. For coal consumption, a global increase of 5.4 % was found in 2011. This is an above average increase, and accounts for 30.3 % of the global energy consumption [36]. Incorporation of the nuclear energy in the energy mix, is an effective way to reduce CO₂ emissions, with the USA, France and Japan leading the way. After the Fukushima accident though, Japan and other countries, like Germany, changed significantly their energy mix, by increasing the share of coal and/or renewable energy sources. Total renewable sources have increased significantly and supply as much as 16.7 % of the global final energy consumption [4]. At least 118 countries, both developing and developed, had set renewable energy targets by early 2012. In Germany, renewables account for 20 % of its total electricity consumption [4]. Asia was the biggest investor on wind power,

accounting for 52 % of the total wind power capacity. Solar energy showed also a significant increase by 75 % globally in 2011. Hydropower however, exhibited the smallest increase, compared to other renewables, by 1.6 % globally since 2003. New policies and regulations, aiming to increase the share of nuclear and renewable energy sources affected the trends in CO₂ emissions globally. Further regulations are needed though to avoid the possible re-emergence of pollution levels, according to the N-shaped relationship between economic growth and pollution. The energy sector is a key factor towards influencing emission levels [5]. But the technical obsolescence should be taken into consideration, since it can diminish the long-term positive effect of the innovation achievements [37].

6 Conclusions and summary

In chapter 2, the most acknowledged Pollution-income relationships (PIR) are discussed. The Environmental Kuznets Curve (EKC) is the most extensive theory and it suggests that the environmental damage increases as the GDP/capita increases up to a point, where the trend is reversed, forming an inverted U-shape curve. Although the EKC-curve is widely used, it has received a lot of critique over the years, concerning the implicit assumption of the EKC-speculation about the normal distribution of income [23] and other factors. The N-shaped relationship is an extension of the EKC-pattern, which could potentially better analyze the long-term relationship between economic growth and environmental degradation. It implies a behavior that amplifies the income-environmental pollution relationship in the long term [27, 28]. The Brundtland curve hypothesis follows the opposite trend (a U-shaped curve) than the EKC-curve, where environmental damage decreases as GDP/capita increases up to a point where the trend is reversed, following to an increase of the environmental damage. However, the mechanisms explaining its decrease are different than for the EKC. For the latter, this occurs at later stages, when the economies have grown, due to international trade, increased demand for a cleaner environment and more effective production. For the Brundtland curve hypothesis, this occurs at the early stage, where reduced poverty could favor the protection of the environment.

The Daly theory predicts that, the environmental damage increases exponentially with the increase of GDP/capita (does not include any type of turning point). The only solution to save the environment would be to adopt a different type of economy, where growth should not increase steadily but held constant (steady-state economy). The scale effect is also responsible for the increase in the environmental damage and is the common denominator for the three most acknowledged theories on the subject.

In chapter 3, a possible solution to the problem of the responsibility of emissions is discussed, namely the comparison of carbon emissions based on both territorial-based production and on final consumption [2, 81]. It is suggested, that carbon emissions are concentrated mainly in few developed countries. Recently though, strongly growing devel-

oping countries have increased significantly their share of total emissions. Emissions associated with consumption are larger than emissions embodied in the production activities of developed countries [2]. Data from the period between 1990 and 2014, indicated that in developed countries, like Germany, United Kingdom and the United States, the consumption-based emissions are higher than the production-based emissions, whereas the opposite is true for the developing countries, like Brazil, China and India. Further, they argue that International trade has helped developed countries significantly to maintain their consumption patterns, that are carbon-intensive, by importing goods and services that are more polluting than their exports [83].

In chapter 4, a geographical analysis takes place. Data from 1960 to 2012 were examined, for Belgium, France, Denmark, Germany and the UK, an absolute decoupling of emissions and economic growth was found, mainly due to the rise of the share of nuclear energy in the energy mix. However, for Finland, the Netherlands and Austria, there is a weak evidence, of emissions and economic growth decouple [88]. For India, from 1976 to 2006, it is reported that CO₂ emissions affect positively the energy use and capital but negatively the GDP and population. On the other hand, energy consumption affects positively the CO₂ emissions and the GDP but negatively the population and the capital. This suggests, that capital and population, namely labor, have been replaced to a great extent by energy use in the production processes. For the case of China, between 1985 and 2005 waste gas, waste water and solid wastes were examined. All three pollutants follow the EKC-pattern and have a long-run co-integration correlation with GDP/capita [93]. Additional data for China from 2000 to 2015, focusing on the air quality index, were analyzed with different improved EKC-models. Co-integration analysis under the three-square model exhibited that the air quality index and the GDP/capita follow the N-shaped curve, whereas the two-square model resulted to a U-shaped relationship between the aforementioned variables. Concerning the middle eastern countries, it was found that in the short-run income has a positive and statistically significant effect on CO₂ emissions in Kuwait, Iraq, Jordan, Qatar and Saudi Arabia [89]. Furthermore, the variables of urbanization and life expectancy were also considered [98]. Life expectancy depends heavily among others on the environmental quality and wellbeing of the population [98]. In the short run, life expectancy exhibited no significant effect on CO₂ emissions for Iran, Bahrain, Syria, Qatar, Oman and UAE. For Jordan, on the other hand, a negative effect at 10 % was found on the CO₂ emissions. This suggests that an increase in life expectancy is feasible only at the expense of increasing emis-

sions. For the case of the USA, the EKC-hypothesis was verified. By decomposing the CO₂ emissions into the factors of population, economic and technological growth, they found that the trend is steadily upwards with a clear seasonal influence on CO₂ emissions [99]. Focusing on the continent of Africa, Congo exhibited economic growth while reducing CO₂ emissions [89]. However, in Mauritius, the EKC-pattern could not be verified, namely human activities increasingly impact the environment. Trade openness and its effect on emissions were found to affect South Africa, Kenya and Togo in a negative way [105].

Finally, in chapter 5, the global CO₂ emissions, the energy mix and the effects of renewables are discussed. Different sources of CO₂ emissions were identified and discussed [36]. Fossil fuels combustion contributes approximately 90 % of the total global CO₂ emissions [3]. Oil and natural gas exhibited an above average increase, accounting for 30.3 % of the global energy consumption [36]. Incorporation of the nuclear energy in the energy mix, is an effective way to reduce CO₂ emissions, with the USA, France and Japan leading the way. The landscape though, changed significantly after the Fukushima accident. Japan and other countries, like Germany, changed their energy mix, by significantly increasing the share of coal and/or renewable energy sources. Total renewable sources have increased significantly and supply as much as 16.7 % of the global final energy consumption [4]. In Germany, renewables account for 20 % of its total electricity consumption [4]. Asia was the biggest investor on wind power, accounting for 52 % of the total wind power capacity. New policies and regulations, aiming to increase the share of nuclear and renewable energy sources affected the trends in CO₂ emissions globally. Further regulations are needed though, to avoid the possible re-emerge of pollution levels, according to the N-shaped relationship between economic growth and pollution. The energy sector is a key factor towards influencing emission levels [5]. But the technical obsolescence should be taken into consideration, since it can diminish the long-term positive effects of the innovation achievements [37].

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